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MANAGING THE U.S. ECONOMY IN A POST-ATTACK ENVIRONMENT: A SYSTEM DYNAMICS MODEL OF VIABILITY

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FINAL REPORT - VOLUME 2

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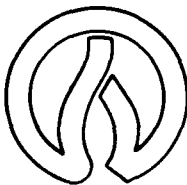
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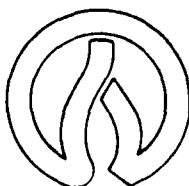
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This report is Volume II of the final report under this contract. Volume I is "Civil Preparedness and Post-Attack U.S. Economic Recovery: A State-of-the-Art Assessment and Selected Annotated Bibliography" by A. Feinberg. Volume III is "Options for Accelerating Economic Recovery After Nuclear Attack" by G. Quester.

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→The primary objective of this study is to determine if post-attack viability (or collapse) is automatic for a given system, or if management actions can influence the outcome. In investigating this problem, the approach focuses on exploring the structure of a post-attack system for instabilities, identifying the processes that could lead to collapse, and then evaluating if and how alternative post-attack management policies can mitigate the effects of those instabilities. →

At the conceptual level, the approach characterized a system's viability in terms of an inventories "race." Since the immediate post-attack period would be marked by a reliance on stockpiles and inventories to sustain the surviving population, the critical question was whether inventories would be depleted before the economy could replenish supplies by reorganizing initial production facilities. Additionally, the study attempted to determine how various types of systemic instabilities can affect this inventories race and how management actions can effectively overcome any debilitating effects. that these instabilities might have on the ability of the nation to recover. These instabilities may appear due to the delays and uncertainties affecting such basic economic support systems as communication and transportation networks, organizational structures and resource allocation mechanisms.

A system dynamics model is constructed of a post-attack economy to study the management problems affecting these support systems in the immediate post-attack period. Through repeated simulations, the model is able to demonstrate the effects of potential instabilities on the performance of the economy and how alternative management policies could mitigate those effects. While the results should be qualified as being preliminary in the sense that this effort is a first pass at the problem, there is sufficient evidence to proceed with a more extended analysis. The evidence suggests that the issue of viability is greatly dependent on effective emergency preparedness policies and resource management actions. The simulation results from the model clearly indicate that viability is not automatic even if adequate productive capacities survive; the same system can produce both viability and collapse depending on the choice of policies and management strategies. If ineffective pre-attack and post-attack policies are followed, the potential for debilitating instabilities arising greatly increases and so, too, does the potential for system collapse.

PREFACE

This report has been written as part of Analytical Assessments Cor-
poration's study of the management of the post-attack U.S. economy. Two
other reports have been written covering other aspects of AAC's research
on the management of the post-attack U.S. economy. They are:

A. Feinberg, "Civil Preparedness and Post-Attack U.S. Economic
Recovery: A State-of-the-Art Assessment and Selected Annotated
Bibliography," AAC-TR-9204/79, October 1979; and

G. Quester, "Options for Accelerating Economic Recovery After
Nuclear Attack," AAC-TR-9203/79, July 1979.

Feinberg's report contains an assessment of the state-of-the-art of
modeling and analysis for civil preparedness and management of the post-
attack U.S. economy. This evaluation was derived considerably from a large
volume of related literature. A selected, annotated bibliography of over
100 entries follows the state-of-the-art assessment.

Literature areas reviewed included historical disasters, industry
studies, post-attack viability, survival and economic recovery, and civil
defense, both U.S. and Soviet. Some literature on modeling methods was
researched. Modeling methods covered were input/output, econometrics,
optimization, and system dynamics.

Analysis of the literature and current state-of-the-art revealed
several key management aspects of the post-attack economy. These aspects
were resource allocation and distribution, energy, information, communi-
cation, command and control (C^3), finance, social and behavioral response,
and government authority. Most of these managerial aspects were found
to have been neither thoroughly analyzed nor specifically modeled.

Assessing modeling needs, available modeling methods, and deficien-
cies in the state-of-the-art led to a recommendation for further develop-
ment of system dynamics models for management of U.S. post-attack economic
recovery. System dynamics is suggested because of its flexibility, poten-
tial scope and capabilities for handling non-linearities, dynamic effects,
and soft items such as social and behavioral responses.

The results of Feinberg's review led to the development of a system dynamics model of the management of the U.S. economy reported on in the present report. The primary focus of this study is to determine if post-attack viability (or collapse) is automatic for a given system, or if management actions can influence the outcome. In investigating this problem, the approach focuses on exploring the structure of a post-attack system for instabilities, identifying the processes that could lead to collapse, and then evaluating if and how alternative post-attack management policies can mitigate the effects of those instabilities.

At the conceptual level, the approach that is taken characterizes a system's viability in terms of an inventories "race." Since the immediate post-attack period would be marked by a reliance on stockpiles and inventories to sustain the surviving population, the critical question is whether inventories will be depleted before the economy can replenish supplies by reorganizing initial production facilities. Additionally, the study attempts to determine how various types of systemic instabilities can affect this inventories race and how management actions can effectively overcome any debilitating effects that these instabilities might have on the ability of the nation to recover. These instabilities may appear due to the delays and uncertainties affecting such basic economic support systems as communication and transportation networks, organizational structures and resource allocation mechanisms.

A system dynamics model is constructed of a post-attack economy to study the management problems affecting these support systems in the immediate post-attack period. Through repeated simulations, the model is able to demonstrate the effects of potential instabilities on the performance of the economy and how alternative management policies could mitigate those effects. While the results should be qualified as being preliminary in the sense that this effort is a first pass at the problem, there is sufficient evidence that it would be profitable to proceed with a more extended analysis. The evidence suggests that the issue of viability is greatly dependent on effective emergency preparedness policies and resource

management actions. The simulation results from the model clearly indicate that viability is not automatic even if adequate productive capacities survive; the same system can produce both viability and collapse depending on the choice of policies and management strategies. If ineffective pre-attack and post-attack policies are followed, the potential for debilitating instabilities arising greatly increases and so, too, does the potential for system collapse.

Quester's report is a companion piece to these two studies. It starts with the conclusion of these two studies, as well as many other studies of the post-attack recovery, that we are likely to fail to exploit to the fullest our potential for economic recovery following a nuclear attack because of failures in post-attack management in both the political and economic sectors. It also presumes that large-scale changes in peacetime arrangements will not win acceptance, so that the best hope for improvement is to look for more marginal adjustments in our continually evolving peacetime management systems, adjustments which might contribute substantially to post-attack recovery at little peacetime cost.

In addition, Quester's report reviews general technological trends in key areas with regard to whether they will tend to make the government reorganization problems easier or harder. Inferences are drawn about relatively inexpensive pre-attack actions, based on exploiting favorable technological trends, which could be taken to make the post-attack management problems more tractable. The report is optimistic, in that it believes that a number of such adjustments deserves to be explored. The post-attack considerations addressed include making government more effective in bringing about economic recovery and, very importantly, making sure that government continues as government, i.e., that we do not sink into anarchy.

This analysis in Quester's report is intended to put upon the table a number of new ideas worthy of further consideration. It is not within the scope of this analysis to evaluate these ideas. Consequently, it may turn out that some of these ideas do not stand up to the scrutiny of further exploration. Nevertheless, this report should serve the important purpose of providing a rich menu of management policies which should be evaluated further.

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I. OVERVIEW

Several studies have examined the problems of national recovery after
a nuclear attack. Overwhelmingly, these studies conclude that if the
nation remains *viable*, recovery is certain to follow. Viability, as the
term is used here, is essentially a race between the drawdown of inventory
and inventory replenishment in the post-attack period. If the rate of the
drawdown of food, medicine, heating oil, and so on exceeds the rate of re-
plenishment over a sufficiently long time horizon, the post-attack economy
will collapse. However, if the drawdown rate is eventually balanced or
exceeded by the replenishment rate, the system is said to be viable and
recovery will follow.

What then influences viability? The answer is relatively simple:
Pre- and post-attack *management* and the *inherent characteristics* of the
social system being managed. Questions about viability can be reduced to
questions about how management and system characteristics singularly and
jointly affect viability. Implicit in this viewpoint is the assumption
that management, properly exercised, can mean the difference between system
viability and system collapse, for if a system's inherent characteristics
effectively guaranteed *a priori* either viability or collapse, *regardless
of the management action taken*, there would be little point in studying
pre- and post-attack management. If, on the other hand, viability or col-
lapse can be demonstrated to be a function of management actions coupled
with system characteristics, the case could be made for studying pre- and
post-attack management as a means of insuring viability. Viewed in this light,
the research question can now be stated: "Given some system, is viability
(or collapse) automatic for that system, or can management by its actions
influence the eventual outcome?"

This approach permits us to determine in a preliminary fashion if via-
bility is independent of management actions. If viability cannot be shown
to be influenced by management actions, there would be little need to focus
resources on further developments in this area. A system would simply be
viable or collapse regardless of what managers do. If, on the other hand,

viability does depend on which set of management policies are actually in effect at the time of and immediately following an attack, subsequent research can then proceed to develop a better understanding of the impacts of pre- and post-attack management to insure national viability.

The basic philosophy of this modeling effort is to construct a model that represents a social system to determine if it contains fundamental instabilities in terms of its inherent characteristics that lead to either viability or collapse, and further, to see if management actions can be introduced that influence these results. For this reason, we are not trying to determine what is likely to happen. Rather, we are attempting simply to discover if and where instabilities might occur and what effect management actions might have on these instabilities.

The results of the research demonstrate that neither viability nor collapse is inherently automatic in a system. When tested under conditions of variable management parameters and policies, the same system produced instabilities leading to either collapse or viability. Thus viability, at least in terms of this model, is not certain but, rather, is directly a function of management actions and interventions both before and immediately after an attack. The remainder of this report discusses in detail the model construction, the background conceptualization of the model, and the policies and parameters that lead to both collapse and viability.

II. BACKGROUND

Several recent studies of the post-attack period underscore the importance of understanding how resource management problems could affect the economic recovery of the nation should a nuclear exchange occur.[1] Bolstered by findings from historical cases of post-war and disaster recovery efforts, these studies conclude that the most critical recovery problems do not involve either the production capabilities of a nation or the availability of raw materials. Rather, the critical problems have concerned management of the surviving resources.

In the situations examined, food and medical supplies, raw materials and finished goods, machinery and equipment have been found to survive in sufficient quantity to provide the economic capabilities for recovery, but locating and matching the surviving resources to the points of need have hampered the recovery operations. The most plausible explanation for this concerns the extent to which economic recovery requires effective resource management; and to be effective, management requires the support of communication and transportation networks, organizational structures, and resource allocation mechanisms. Not unexpectedly, these supporting systems have not been as efficient or as reliable as they are in a normally functioning economy.

Such resource management problems would be more acute during the period immediately following a nuclear exchange. Cognizant emergency preparedness agencies would require accurate information as to what resources are needed where, where those resources are located, and how those resources can be allocated equitably and transported to the points of need. Again, to

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[1] See for example, C. R. Neu, *Economic Models and Strategic Targeting* (U), The Rand Corporation, R-1864-ARPA, June 1976, SECRET; H. M. Berger, *A Critical Review of Studies of Survival and Recovery After a Large-Scale Nuclear Attack*, R&D Associates, RDA-TR-107006-009, December 1978; and A. Feinberg, *Civil Preparedness and Management of the Post-Attack Economy: A State-of-the-Art Review*, Analytical Assessments Corp., AAC-TR-9204/79, September 1979.

accomplish this would require efficiently functioning support systems. The problem, however, is that the immediate post-attack period is likely to be characterized by such problems as communication systems that provide incomplete and/or contradictory information, transportation systems that can not function due to failures to match vehicles with drivers and fuel supply points, and organizational structures with competing lines of authority that create delays and confusion in resource allocation decisions. As summarized by one writer, the major problems will be in developing the transportation, communications, and organizational capabilities required to bring these resources to bear at the points where they are needed.[2]

Given these circumstances, it appears highly probable that at the point when the nation is in greatest jeopardy, there is also the greatest potential for instabilities arising that would lead to the collapse of the system. Obviously, careful pre-attack planning of post-attack management policies is needed to help mitigate the effects of these potential instabilities and thus improve the nation's chance for timely recovery to its pre-attack status as a major world power.

It is somewhat ironic that while effective resource management policies are recognized as being critical for economic recovery, little attention has been paid to the problem of properly measuring the impact of various post-attack management policies on the performance of the economy. For example, what effects do inventories of key supplies and equipment and their pre-positioning have on the performance of the post-attack economy? what are the critical delays that will degrade economic recovery? where are those delays found in the communication and transportation networks? in the organizational structures? what effects do alternative allocation mechanisms have on productivity?

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[2]S. G. Winter, Jr., *Economic Viability After Thermonuclear War: The Limits of Feasible Production*, The Rand Corporation, RM-3436-PR, September 1963.

A major reason for the inattention is that those studies that investi-
gate post-attack economic recovery typically assume that since sufficient
production capabilities and resources will exist after a nuclear exchange,
it is only a matter of time before the growth of the economy begins anew.
In other words, it is only a question of when. But, if it is possible to
show that with the same initial conditions after an attack, the economy of
the nation can remain viable or collapse depending on which post-attack
management policies (and in some cases, pre-attack policies) are selected,
the need for exploring the problem of economic viability would be undeniable.

The present study reports on research investigating this problem.
The central task was to explore the structure of the post-attack economic
system for instabilities, identify the processes that would lead to its
collapse, and then evaluate if and how alternative pre-attack preparations
and post-attack management policies could mitigate the effects of those
instabilities.

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III. APPROACH

The critical first step in any modeling effort is to develop a conceptual model of the "real" world system that is being studied. This conceptual model then forms the basis for the simulation model that will be constructed. Since there are many different ways to conceptualize any "real" system (different levels of aggregation, different structural components chosen for particular emphasis, and so on), considerable thought should be given to the question of what you want the model to be capable of demonstrating.

The present case is no different; several caveats have guided the selection of both the general modeling approach and the specific elements included in the model. At the conceptual level, the most important initial consideration has been our characterization of the system serving as the "real" world referent: post-attack economic viability. We framed the model in terms of an inventories "race." The analogy is useful in that immediately after any nuclear exchange, there would be a period during which the surviving population would be sustained by pre-attack stockpiles and inventories. Shortly thereafter, efforts would begin to reorganize the economy to start up production of critical supplies and materials.

Winter, who first presented the conceptual notion of an inventories race to depict the problem of post-attack viability, succinctly characterized the challenge of post-attack management:

> Unless production of the necessities of life
> can be resumed, whatever success there has been
> in protecting the population from the imme-
> diate consequences of the war will dissipate
> as supplies of food, medicines, and heating oil
> disappear; the surviving thermal generating
> plants exhaust their supplies of coal and fuel
> oil, and starvation, disease, and exposure take
> their toll.[1]

---

[1] S. G. Winter, Jr., *Economic Viability after Thermonuclear War: The Limits of Feasible Production*, p. 10, The Rand Corporation, RM-3436-PR, September 1963.

In other words, it is during this period that the race will be won or lost. If the rate of drawdown on inventories exceeds the rate of replenishment over a sufficiently long period, the scenario depicted by Winter would emerge and the post-attack economy would collapse. If, however, the draw-down rate is eventually balanced or exceeded by the replenishment rate, the system would become viable and recovery would follow. Conceptualized in this manner, the first requirement is to construct a model with the capability of testing for systemic instabilities likely to influence the outcome of the race.

A second general requirement of the model concerns its ultimate use. Although the general focus of the model concerns the instabilities affecting the inventories race, the model must be capable of evaluating the effects of alternative post-attack management policies on those instabilities identified in the system. Without this capability, it would be impossible to answer the basic question of whether or not it is possible to demonstrate how the same system can collapse or remain viable depending upon the emergency preparedness policies adopted in the post-attack period.

The third requirement for the model is more specific. It concerns the inputs and constraints that would operate in the model. Since it is highly likely that post-attack demand would be radically different from pre-attack demand, the model should not utilize pre-attack coefficients in the equations depicting post-attack economic relationships. For example, where productivity may be primarily a function of capital investment in the pre-attack economy, productivity in the post-attack economy may depend heavily on the availability of food and heating oil and only to a lesser extent on the capital available. It is not likely that this relationship between subsistence level and productivity would emerge in an econometric model, for instance, where economic behavior is depicted by equations derived from the modeler's understanding of a normally functioning economy.

A fourth, and related requirement for the model pertains to the nature of the relationship between economic inputs and outputs. Characteristically, input/output relationships are represented as being linear, a specified amount

of input "x" results in a specified amount of output "y" with increments
of "x" resulting in linear increments of "y." In the post-attack economy,
the situation would be quite different due to the level of damage and destruc-
tion. For example, if a significant portion of an industry's capacity
has been destroyed, linear incremental inputs will not result in correspond-
ing linear increments of output. Thus, the model must be capable of operating
with non-linear production factors.

Delays will be inevitable in the post-attack economy. Thus, a fifth
requirement of the model is that it be capable of simulating the various
delays that would affect the start-up of production. Examples would be
delays affecting transportation, retraining labor, information flows, deci-
sion times, repair and replacement times, and the lead times affecting prod-
uction processes. These delays would not be uniform nor would they be iso-
lated in their effects. Two or more delays may create either synergistic
or unwelcomed higher order effects in the system. Since these delays and
their effects are an essential feature of the instabilities we are searching
for, their inclusion is critical to the overall effort.

A sixth requirement of the model is that it not operate under steady-
state or static conditions. The immediate post-attack period is indelibly
marked by dynamic time dependencies that cannot be ignored in evaluating
the viability race. These include resource allocation decisions, time
lags in production and distribution cycles as well as inventory depletion
and capital accumulation for investment. A model operating with steady-
state assumptions would miss several of the fundamental sources of insta-
bilities that could lead to the system's potential collapse.

Uncertainty is also a major factor to be considered in analyzing post-
attack viability. Uncertainties abound, particularly in the period immediately
following an attack when recovery operations are beginning and the information
critical to their success is at best incomplete and at worst unreliable.
Thus, a seventh requirement of the model is that it be capable of operating
with variable uncertainties about the delays that will affect recovery.

An eighth consideration for the model is that it be able to optimize management policies. Such optimizations may be applied either as a procedure integrated into the model or as a "front-end" to a compatible simulation model. Basically, what is required is that procedures be used to run through the model's variables to determine the 'best' outcome.

A ninth requirement of the modeling approach is that it be able to operate at different levels of aggregation. Structurally, the model will consist of several sectors that represent various subsystems of the post-attack economy. To minimize the amount of time required for detailed data collection, the approach should follow a "top-down" procedure for constructing the model. In this manner, the aggregate representations of the post-attack economy would be used to capture its essential features during this viability phase, and then those sectors which are the most likely to produce potential instabilities would be expanded and further disaggregated to explore those instabilities further.

A tenth and final requirement of the model also concerns the use of "hard" data. Actually, data are less a requirement for a modeling capability than a general strategy for approaching the modeling problem. Given the approach noted above concerning the use of aggregate levels to represent the model's subcomponents, it should be apparent that the modeling approach we espouse is one in which patterns of outcomes cast in terms of rough approximations are favored over precise point estimate results. For one thing, the data requirements for precision are enormous and even then point-estimate precision remains elusive except for the most immediate temporal points. Moreover, the modeler typically becomes rapidly bogged down in Herculean data gathering efforts only to discover in the long run that those data efforts were not required for each subcomponent at the level of detail needed to investigate the phenomena of interest.

Also, since the primary research interest is in discovering whether post-attack management could make the difference between viability or collapse, the model only has to be able to produce both outcomes (viability and collapse) through general policy and parameter adjustments. Extensive resources would not have to be focused on precisely calibrating the model

with detailed data sets. In effect, what this modeling strategy means is
that we have chosen to explore the general behavior of the system in an
attempt to identify the potential regions of instability, given the general
parameters and policies that may exist. While a more precise determination
of these parameters would be required for specific recommendations, the
general approach followed in the present effort is more than adequate to
answer the proposed research question.

Given the array of requirements and capabilities presented in the pre-
ceding discussion, the most appropriate modeling approach was found to be
system dynamics. System dynamics is essentially a simulation modeling para-
digm (that incidentally utilizes a specialized, tailor-made, and highly
efficient programming language, DYNAMO) that aids modelers in conceptual-
izing, formulating, and operating models of "real" world systems. System
dynamics was developed initially by Jay Forrester and his colleagues at
Massachusetts Institute of Technology to aid in understanding the dynamic
behavior of complex systems. Fundamentally, system dynamics views systems
as being comprised of components that are connected in circular, interlocking,
and time-delayed manners and that the structures and processes that com-
prise these systems are equally important as the behavior characteristics
of the system components themselves.[2]

System dynamics has several recommending attributes. First, and per-
haps foremost, is the fact that this approach views systems as a series of
interlocking feedback loops and it is the feedback that produces the behavior
of the system over time. As stated earlier, system instabilities represent
the focus of the present research effort. It is therefore entirely appro-
priate that a technique be used that analyzes system behavior in terms of
positive and negative feedback loops since these two types of feedback loops
and their combinations can produce the instabilities of interest.

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[2] See Jay W. Forrester, *Industrial Dynamics*, Cambridge: MIT Press,
1961; and *Principles of Systems*, Cambridge: Wright-Allen Press, 1968.

A second recommending feature, related to its feedback loop aspect, is that system dynamics has been demonstrated as an effective analytical technique for evaluating the effects of alternative policies on system behavior. Several notable studies have been conducted in such diverse fields as urban and regional studies, industrial production and marketing, criminal justice, energy policy, economics, and international systems. In each case, the models developed to study these systems have examined the systemic behavior under a variety of assumptions concerning policies that may influence the ultimate fate of the system under question. Perhaps, the report to the Club of Rome (*The Limits to Growth*) provides the strongest evidence of the policy orientation of the system dynamics approach.

At a more specific level, system dynamics is useful because of its versatility. For example, non-linear relationships are readily accommodated. In fact, system dynamics can operate with many types of non-linear relationships that help produce exponential, sigmoidal, or even oscillating system behavior. Similarly, the technique focuses on both negative and positive feedback loops and in the context of these loops, effects produced by delay mechanisms can easily be examined. And finally, the data requirements of system dynamics are such that highly aggregated representations can be used to model any system initially. More importantly, once the sensitivity of each structural component and its appropriate feedback loops are identified, those that are the most sensitive can easily be disaggregated and more precise bounds can be determined. The modeler is not required to disaggregate every structural component to provide a consistent level of analysis.

In summary, given the requirements of the research task and characteristics of the system dynamics approach, the application of this particular dynamic simulation technique seemed an obvious way to proceed.

IV. MODEL DESCRIPTION

Winter's early study of the limits of feasible production in a post-attack economy is one of the earliest quantitative treatments of the problems posed by limited resources and technological capabilities in the post-attack period.[1] While Winter did not address the organizational problems involved in the post-attack economy (although he discusses them qualitatively in a later paper), he did offer a definition of what constitutes viability and presented a simple model of the technological requirements for achieving economic viability. According to Winter:

> An economy is viable if it is functioning and capable of producing, without external aid, an output sufficiently large and appropriate in composition to:
>
> (a) provide its workers and their families with a level of consumption high enough to maintain their productivity and to give them the incentive to continue to contribute their services to the economy in a socially productive way;
>
> (b) meet any fixed claims on its output that may exist;
>
> (c) maintain the stock of real capital (including inventories) required to accomplish (a) and (b).[2]

Using this definition, Winter goes on to note that since it is unlikely that the economy would be capable of meeting these requirements in the immediate post-attack period, the problem is to reorganize the surviving resources to provide for a viable economy. Again, although Winter disregards "effects of the war on social arrangements by which economic activity is guided," Winter argues that explanations for non-viability would be narrowed to the fact that critical segments of capital stock

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[1] S. G. Winter, Jr., *Economic Viability after Thermonuclear War: The Limits of Feasible Production,* The Rand Corporation, RM-3436-PR, September 1963.

[2] Winter, 1963, p. 17.

(including labor skills) would be lost. Thus, economic viability could be achieved, from the technological perspective, if the remaining capital stock (inventories and skills included) is both adequate in size and composition to:

> (a) restore the capital stock to a level and composition consistent with viability;
>
> (b) meet any fixed requirement that may exist;
>
> (c) support the members of the labor force and their families at a level sufficiently high to prevent a significant reduction in the labor supply available for the reorganization effort.[3]

The diagram in Figure 1 depicts graphically the essential elements of Winter's model. Time is the critical element in the "inventories race" of which there are two basic outcomes. Either the production capacity (K_o) of the economy will be sufficient to achieve the viability threshold $(\overline{K})$ and meet the requirements noted above (represented by the solid line K_o) or, that capacity will not be achieved, inventories (S_o) will be depleted, and the economy will collapse (represented by the dashed line).

Winter's framework for analysis is extremely useful in that it focuses attention on and underscores the importance of understanding the fundamental problem in achieving viability: restoring productive capacity before inventories are depleted. Although highly aggregated and admittedly preliminary, Winter's approach and framework provide a useful point of departure for the present modeling efforts.

While Winter was interested in determining the technological constraints on achieving economic viability, the present effort expanded the analytic domain to include the organizational aspects that would affect the outcome

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[3] Winter, 1963, p. 18.

FIGURE 1

SUCCESS AND FAILURE IN ACHIEVING VIABILITY

$$t_v \cdot \frac{S_o}{cL}$$
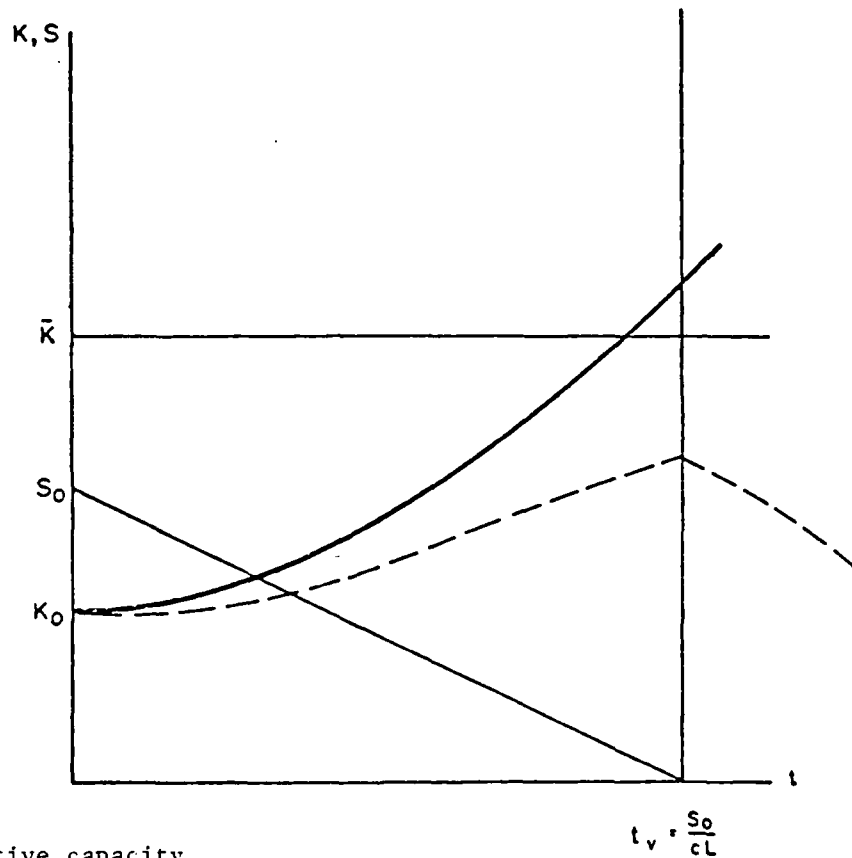
K = Productive capacity

S = Inventory of food

$\frac{L}{\bar{K}}$ = Labor

$\bar{K}$ = Productive capacity required for viability

S_o = Food inventory at end of survival period

K_o = Productive capacity at end of survival period

t_v = Time of depletion of food inventory

S_o/cL = Ratio of food stock to food requirements per period

From Winter, 1963, p. 22.

of Winter's inventory "race." By expanding the analytic framework to include these organizational aspects, many of the critical resource management problems could be examined. It was noted at the outset of this report that historical case studies reveal how post-war economic recovery has been hampered due to inefficient communication and transportation networks, organizational structures, and resource allocation mechanisms—the basic support systems for effective resource management.

The pilot model we developed for studying these resource management problems in the immediate post-attack period focuses on these support systems since they represent the sources of instabilities that ultimately determine the viability of the nation. The central question is what conditions lead to these instabilities and how can alternative emergency preparedness policies mitigate their effects?

To answer these questions, a system dynamics model was constructed of a post-attack economy using Winter's model as a point of departure. The behavior of this model reveals the sources of instabilities in the post-attack economy and identifies their characteristic effects on the performance of the economy. Through repeated simulations, insights are gained as to how alternative emergency preparedness policies can mitigate the effects of these instabilities and insure viability and the eventual recovery of the nation.

The model was developed in several stages with each stage representing an enhancement and refinement over the previous stage. The current version, PAM4 (Post-Attack Model No. 4), operates with four basic sectors that represent the structural components of the post-attack economic system. These four are capital plant and equipment, intermediate products, labor, and food supplies. The food supply sector is further disaggregated into production, transportation, and distribution (called matched food supply) subcomponents.

These sectors and subsectors are interrelated through interlocking feedback loops that depict the interaction of these sectors in terms of information and material flows. Figure 2 presents this feedback loop structure. It is a causal loop diagram of the post-attack system that defines

FIGURE 2

CAUSAL LOOP DIAGRAM

SUPPLY DRAWDOWN VERSUS SUPPLY REPLENISHMENT
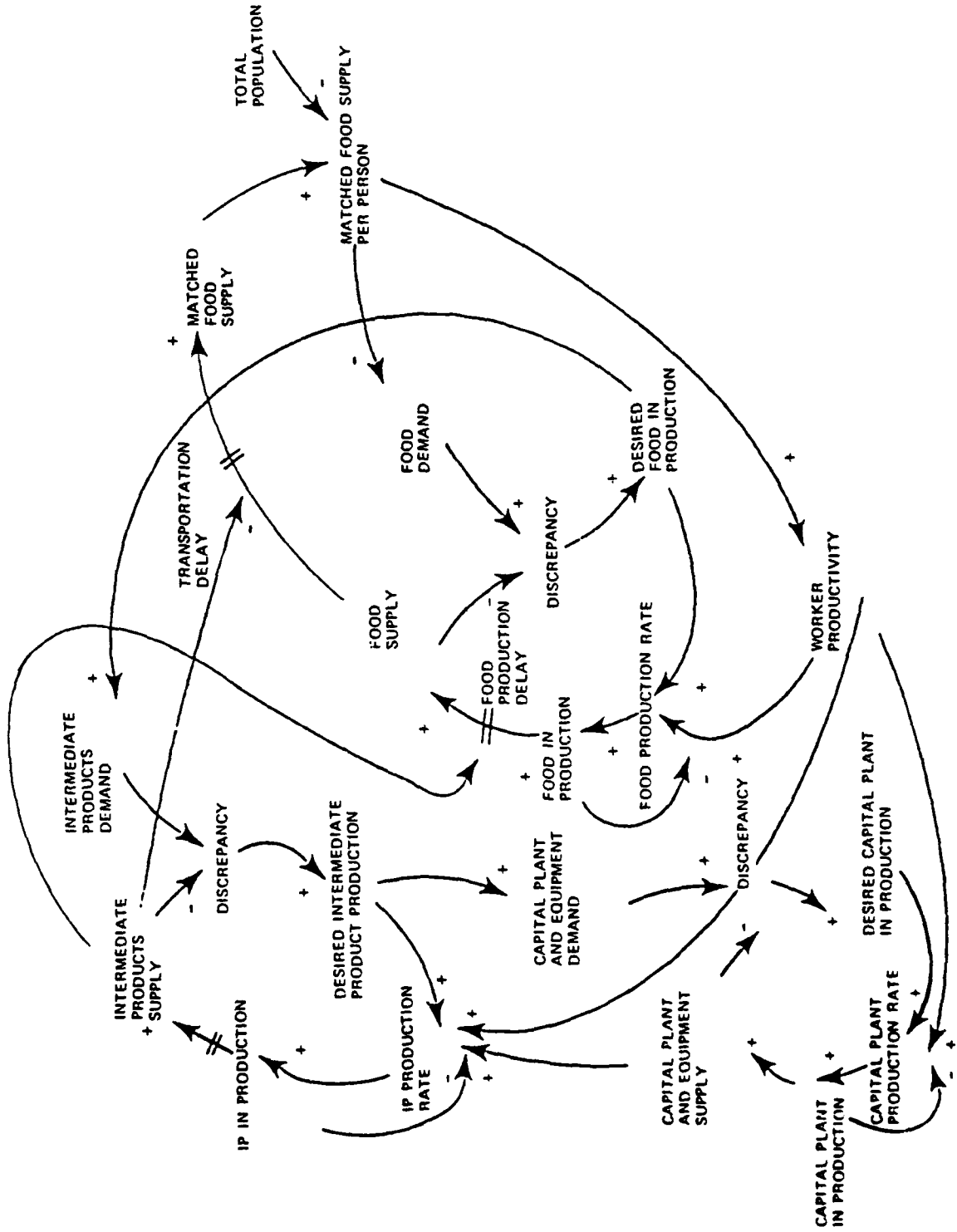
the basic causal relationships between the system variables. The causal
relationships cluster into the feedback loops structure shown in Figure 2.

Several feedback loops are presented in Figure 2. The arrows indicate
the direction of the causation between variables while the (+) and (-) signs
indicate the direction of causal influences. For example, the amount of the
matched food supply available per person affects the worker productivity in
the same direction, a positive manner in this example, i.e., the greater the
food supply per person the higher the worker productivity. Worker producti-
vity influences the food production rate which in turn affects the amount of
food in production that determines the size of the food supply. Depending
on the transportation delay, the food supply affects the matched food supply
that then determines the matched food supply per person; thus completing the
feedback loop.

Obviously other factors also operate in this feedback loop such as
the availability of workers and transportation and the effect of information
inputs to determine how much and what types of food need to be produced
and where it should be distributed. Appendix A contains a complete listing
of the model's equations which can be consulted to obtain a more complete
understanding of the system's structure and operating relationships.

Figures 3 through 6 display the causal loop relationships operating
in PAM4 (see Figure 2). Basically, each diagram depicts the interrelation-
ships between food shortage, worker productivity a..d demand, and inventory
drawdown and replacement rates in the respective sectors of the model. The
cross-hatches appearing on selected arrows indicate that a delay operates
between the two points. For example, retraining delays affect the reassign-
ment of workers from a general labor pool to individual sectors, transpor-
tation delays affect the distribution of food, and production delays reflect
the time required to grow food or produce intermediate products.

FIGURE 3

CAPITAL SECTOR
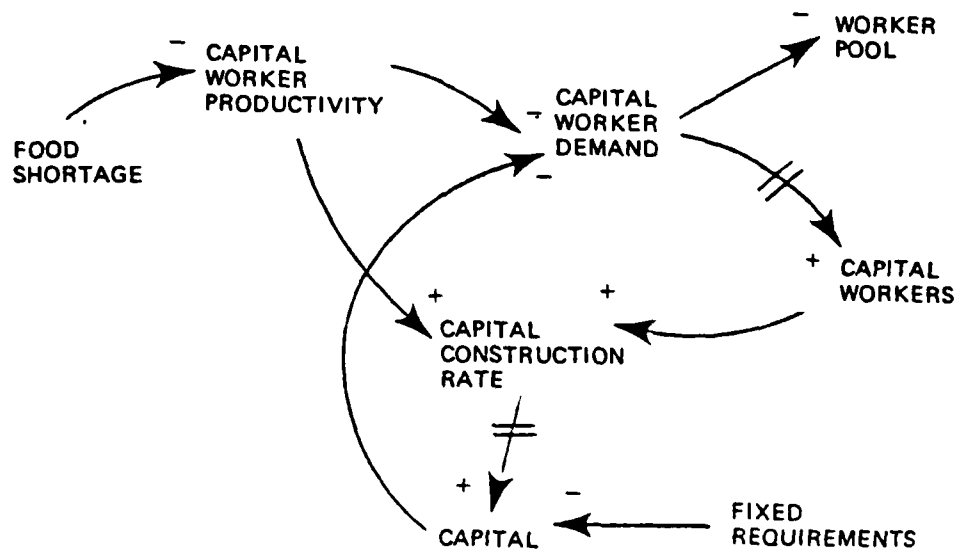
FIGURE 4

INTERMEDIATE PRODUCTS SECTOR
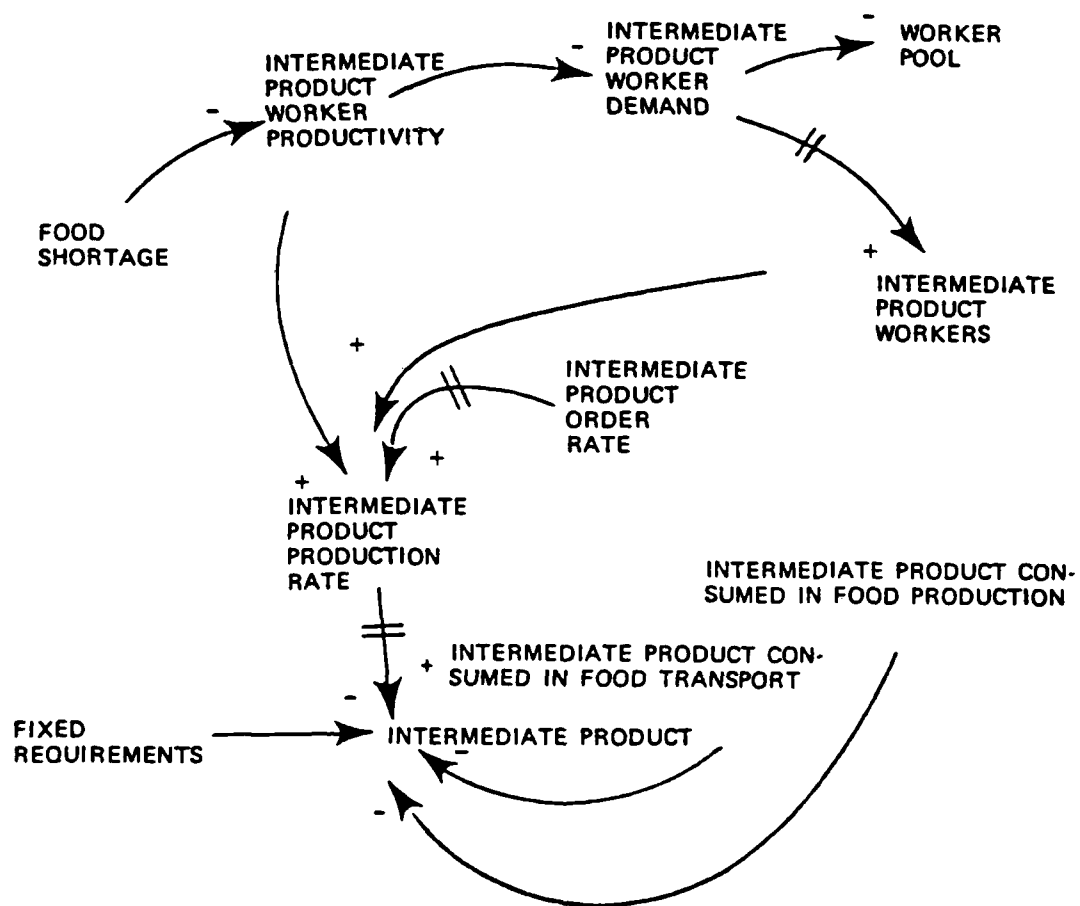
FIGURE 5

FOOD SECTOR

- 22 -
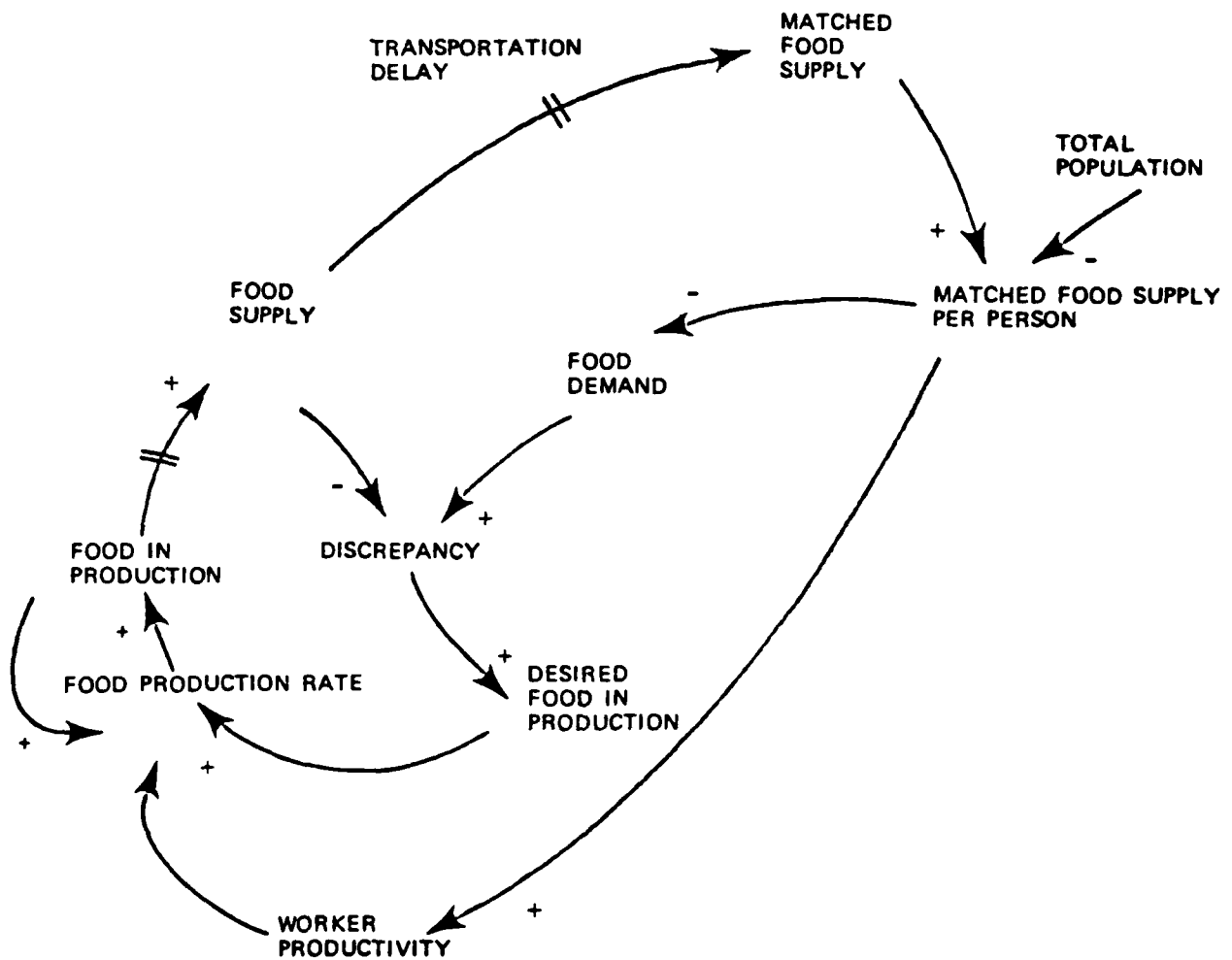
FIGURE 6

WORKER POOL
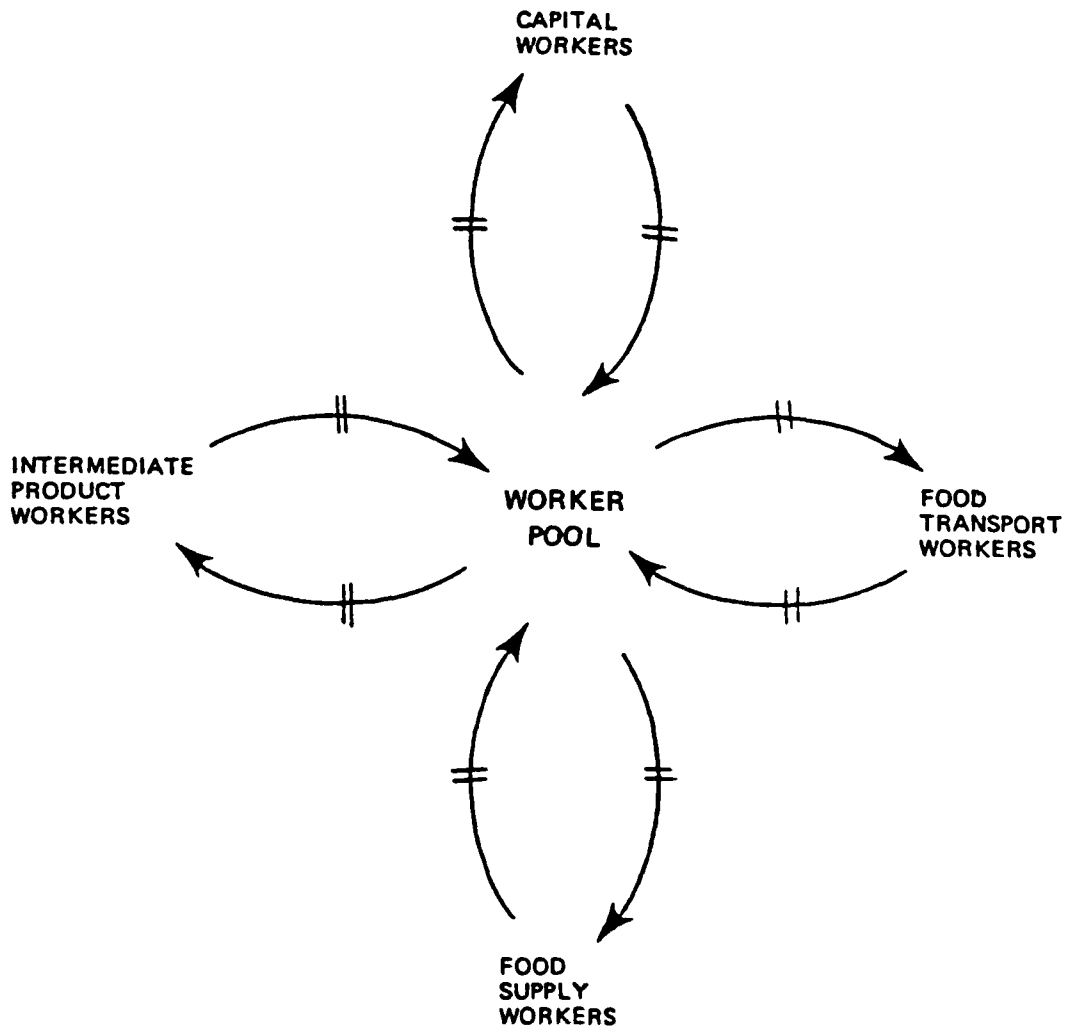
V. MODEL PARAMETERS

PAM4 served as the basis for examining the potential instabilities affecting post-attack economic viability. (Recall that the strategy was to develop cases in which the same model structure would produce collapse or viability as a function of the management policy variables selected to represent the model's operating parameters.) Since the current research interest centered around discovering whether viability is in fact an issue in post-attack management, the effort focused on whether or not the same model could produce both outcomes--collapse and viability--by adjusting these policy parameters rather than on trying to establish with any great accuracy the specific parameters characterizing the existing system. The rationale for this approach is simply that if viability cannot be shown to be a potential problem, there is little need to focus extensive resources on developing exact sets of numbers and policies for precise calibration of the model. If, on the other hand, viability cannot be demonstrated as a certainty, and it in fact depends on which sets of numbers and policies are actually in effect at the time of an attack, subsequent research efforts can then focus on improving the model's precision.

The search for instabilities focused on the key operating parameters in PAM4. These parameters represent areas in which alternative management policies can be implemented to influence and direct the system. They include:

- the effect of initial conditions on the model, i.e., the amount of product on hand and in the pipeline for each sector;

- the effect of food shortages on labor productivity;

- the effect of communication delays in ordering food supplies for distribution;

- the effect of various combinations of external fixed requirements that draw on each sector's inventories;

- the effect of rising expectations concerning food supplies as time progresses in the post-attack period;

- 23 -

- the effect of labor allocation rules on overall econo-
  mic performance; and

- the effect of time delays associated with locating and
  retraining labor as workers are transferred between
  sectors.

Each of these parameters has a range of values associated with it
that were used in repeated simulations of PAM4. Since each parameter con-
tains more than one value, the model could be tested under a variety of
conditions by varying any combination of parameter values. For example,
the tests for instabilities could be conducted under conditions of high or
low fixed external requirements, short or long communication and labor
allocation delays, high or low levels of stockpiles, and so on. The following
section presents the results of these simulation tests.

VI. RESULTS

The results of the simulation tests of PAM4 offer a number of useful insights regarding the nature of the instabilities affecting post-attack viability and lead to several conclusions concerning the effects alternative post-attack management policies have on those instabilities. Thus, the following discussion presents the results in terms of changes in the behavior of the system brought about through changes in its operating parameters and policies. In presenting these results, several choices exist for characterizing the behavior of the modeled system. Another way to state this is to say that various objective functions can be used to describe how the system's behavior changes under alternative operating conditions. The level of capital or intermediate product stocks, worker productivity, or food supplies represent, singularly or in combination, potential objective functions. In the present case, we have selected the amount of matched food available per person (MFAPP) as the primary criterion for assessing the system's performance. Since viability has been characterized as a 'race' between inventory drawdown and replenishment and since food represents a fundamental factor in worker survival and productivity, selecting this variable as the objective function seemed an obvious choice.

Simulations of the PAM4 model were run over a 24-month period, a time span that is generally regarded as the upper bound for the nation to regain viability. Since PAM4 is intended as a viability model, it does not include any capability for assessing economic damage in the trans-attack period. In other words, the model's calculations assume that an attack is over and that the initial conditions characterizing the system reflect the economic damage that occurred.

The results of the simulation test runs are presented in a framework similar to that used by Winter and presented previously in Figure 1. Like Winter, the results presented here examine the behavior of the system over time (the x-axis) but unlike Winter's conceptualization, our results employ the variable MFAPP as a surrogate for the productive capacity (K) and inventory of food (S). (Three times subsistence level is considered to be the

normal level of food consumption, as indicated on the y-axis of the graphs depicting the simulation results.) Similarly, where Winter denoted $\overline{K}$ as the productive capacity necessary to achieve viability, we have selected a subsistence level of matched food supplies (F_s) to represent the viability threshold. Thus, in interpreting results, if the simulation tests reveal the system to be operating below this subsistence level (F_s) for an extensive period of time, the conclusion would be one that points to a pervasive system instability rendering the economy non-viable given the operating policies and parameters of that particular simulation test.

The results from the first set of simulation tests from PAM4 are displayed in Figure 7. These curves depict system viability versus non-viability as a function of the initial conditions of the nation's food supply stockpile when a subsistence level food rationing policy has been initiated immediately following a nuclear attack. The first curve (presented in Figure 7 on the left) represents initial conditions under which the population has a matched food supply (on-hand) of one month at a (40 pound/month per capita) subsistence level, and another month of food supplies inventories at remote production and distribution points. Clearly, the system portrayed by PAM4 and the pre-attack conditions (food stockpiles) and post-attack management policies (subsistence level rationing) do not constitute a viable system.

Figure 7 also displays the results of PAM4 simulations when food supply inventories (not co-located with consumers) were set at six- and twelve-month levels. Given an initial condition of a six-month stockpile, the subsistence level is maintained for five months then drops below this level for approximately four months. As seen in Figure 7, a turn-around occurs at month 15 when the matched food supply begins to decrease, leading to the eventual collapse of the system. When simulated using an initial condition of a 12-month food supply stockpile, this downturn does not occur. The amount of food available per capita remains above the subsistence level after the brief drop between the fifth and tenth month.

Figure 8 presents the results of a second series of simulations. In these simulations, the same parameters and policies as those in Figure 7

FIGURE 7

VIABILITY AND FOOD SUPPLY
(1 MONTH MATCHED FOOD SUPPLY ON HAND)

- 28 -
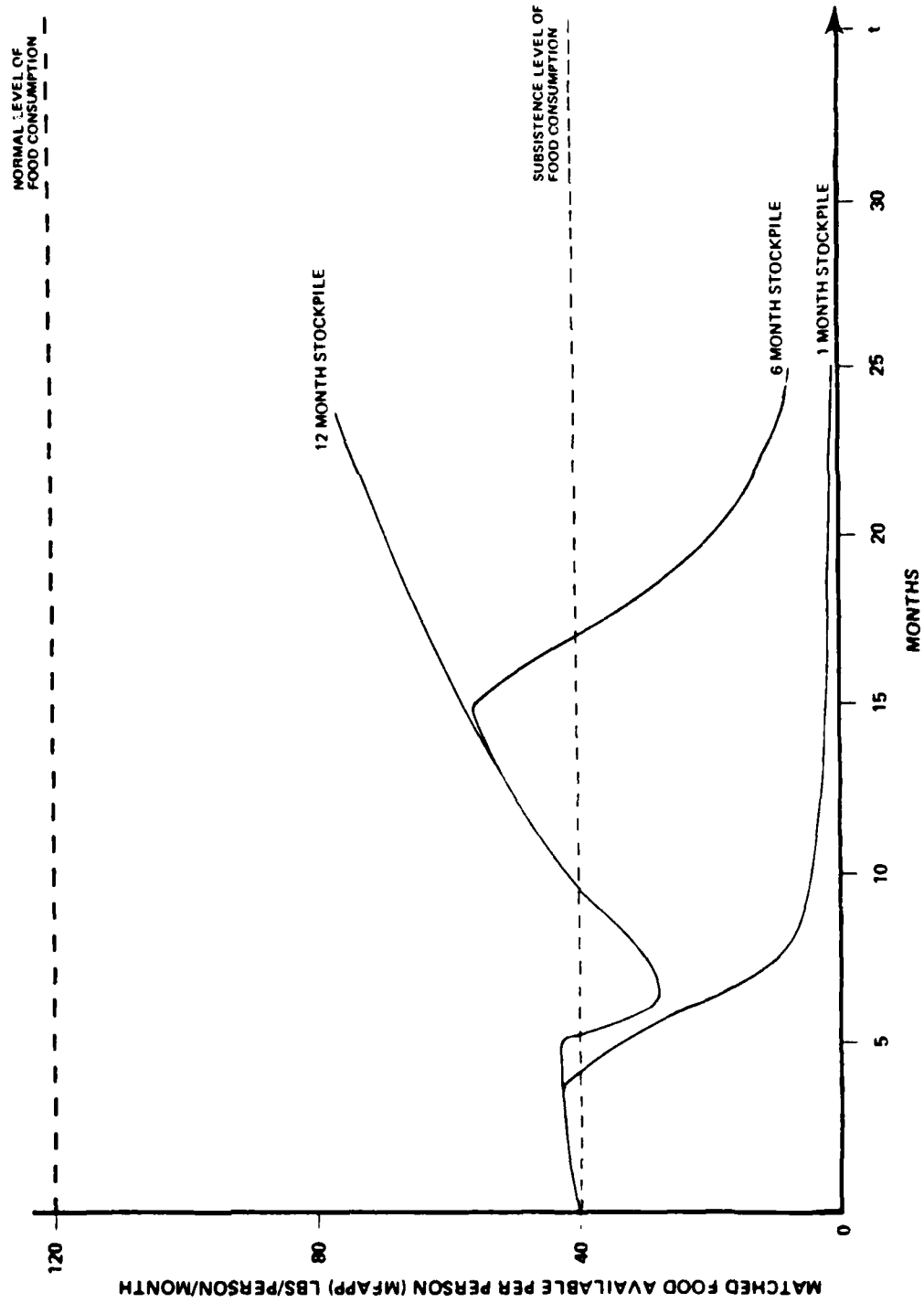
FIGURE 8

VIABILITY AND FOOD SUPPLY

(2 MONTH MATCHED FOOD SUPPLY ON HAND)
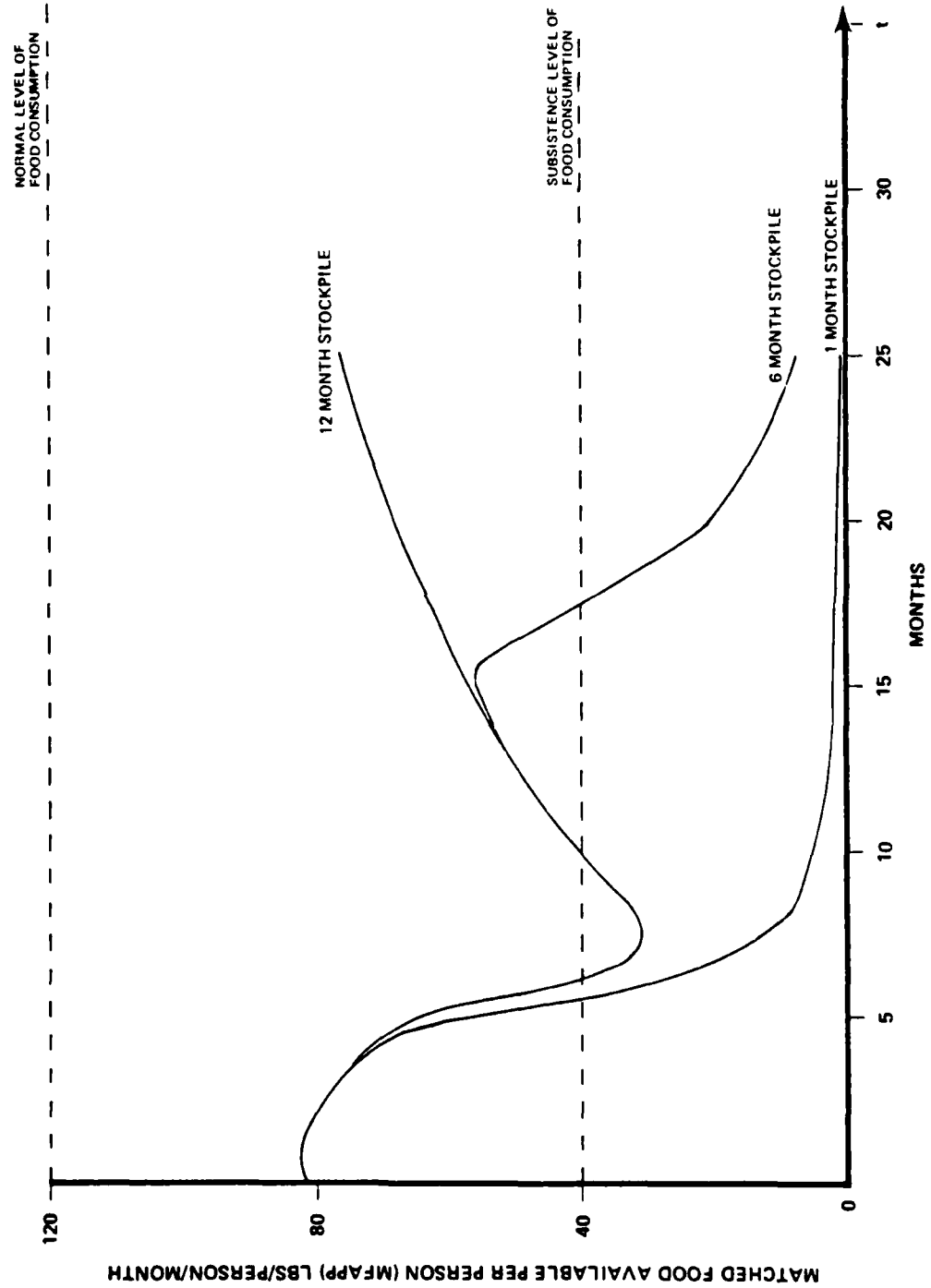
were used except that the initial amount of food available per person (co-located with consumers) was set at twice the subsistence level. The results for the three cases (1-, 6-, and 12-month stockpiles) examined previously reveal once again that viability conditions are met in only one case—the 12-month food supply stockpile.

Figure 9 extends the analysis by presenting the simulation results using initial conditions in which the matched food supply was set at three times the subsistence level. Again, only the 12-month stockpile case met the viability condition.

The results displayed in Figures 7 through 9 reflect post-attack management policies and procedures that are operating under favorable conditions. For example, the communication and transportation delays that affect management activities have been set at one month in these simulations of PAM4. In this sense, the system has been simulated using favorable conditions. More realistically, however, the post-attack period will probably be characterized by longer transportation and communication delays than have been used in the example runs thus far.

Figures 10 through 12 present the results of PAM4 simulations when longer transportation delays are introduced into the system. These simulations were run using the assumptions of a 12-month food supply stockpile and three different initial conditions regarding the availability of matched food supplied (those supplies on hand that do not have to be transported and distributed). Figure 10 is based on a matched food supply at subsistence levels, Figure 11 at twice subsistence levels, and Figure 12 at three times subsistence levels. The solid line reflects the undelayed system while the dashed line portrays the effects of an initial three-month delay in transporting and distributing the food supplies to the points of need.

As seen in these figures, the introduction of these transportation delays significantly degrades the performance of the post-attack economy as measured by the level of the matched food supply available per person. Although the simulation results for each case show food availability, returning above the threshold level, the nature of the recovery raises an interesting question; namely, how long can food availability remain below subsistence levels before the system collapses? In both Figures 10 and 11,

FIGURE 9

VIABILITY AND FOOD SUPPLY

(3 MONTH MATCHED FOOD SUPPLY ON HAND)
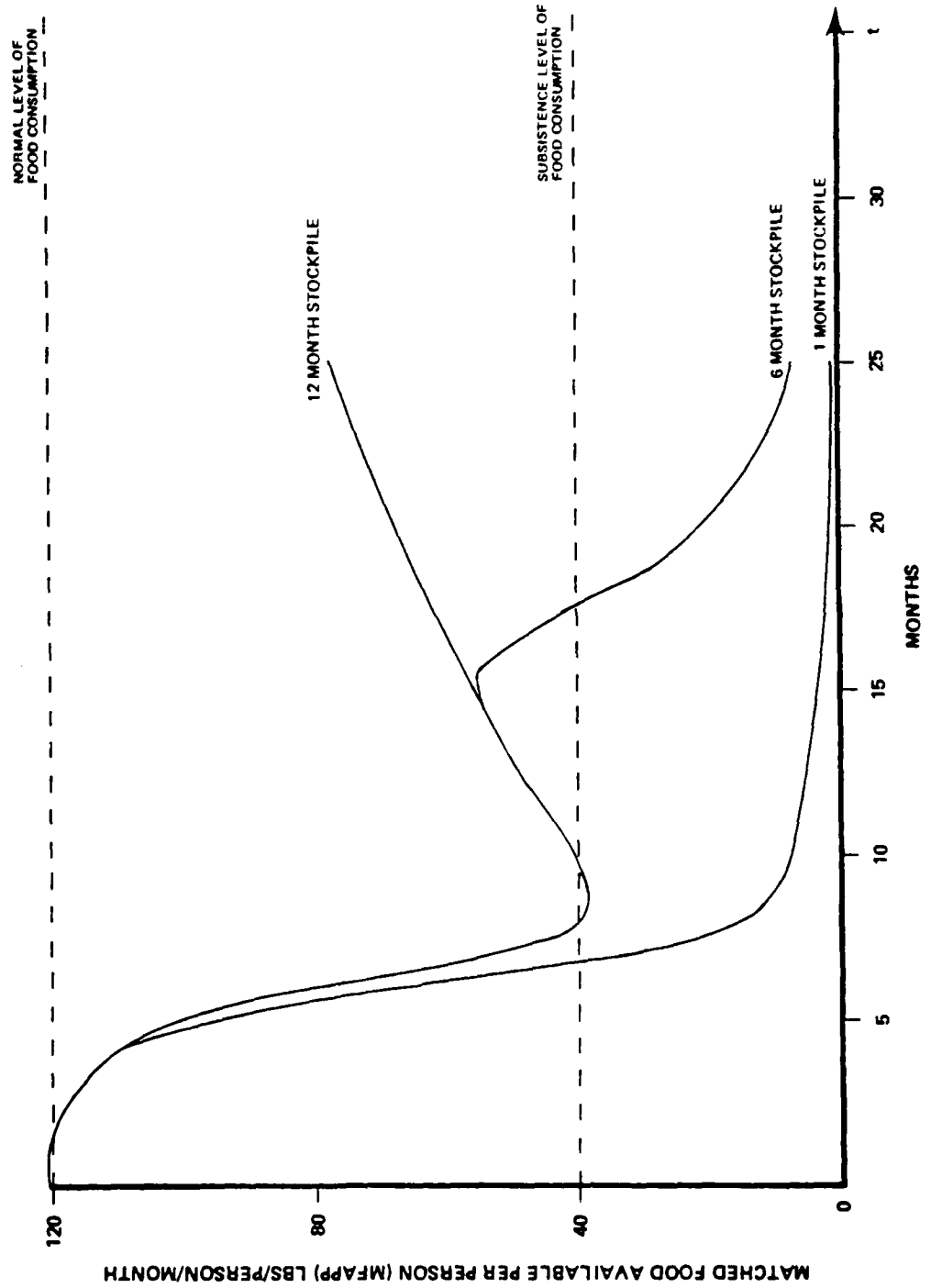
FIGURE 10

VIABILITY AND FOOD SUPPLY WITH TRANSPORTATION DELAY

(1 MONTH MATCHED FOOD SUPPLY ON HAND)
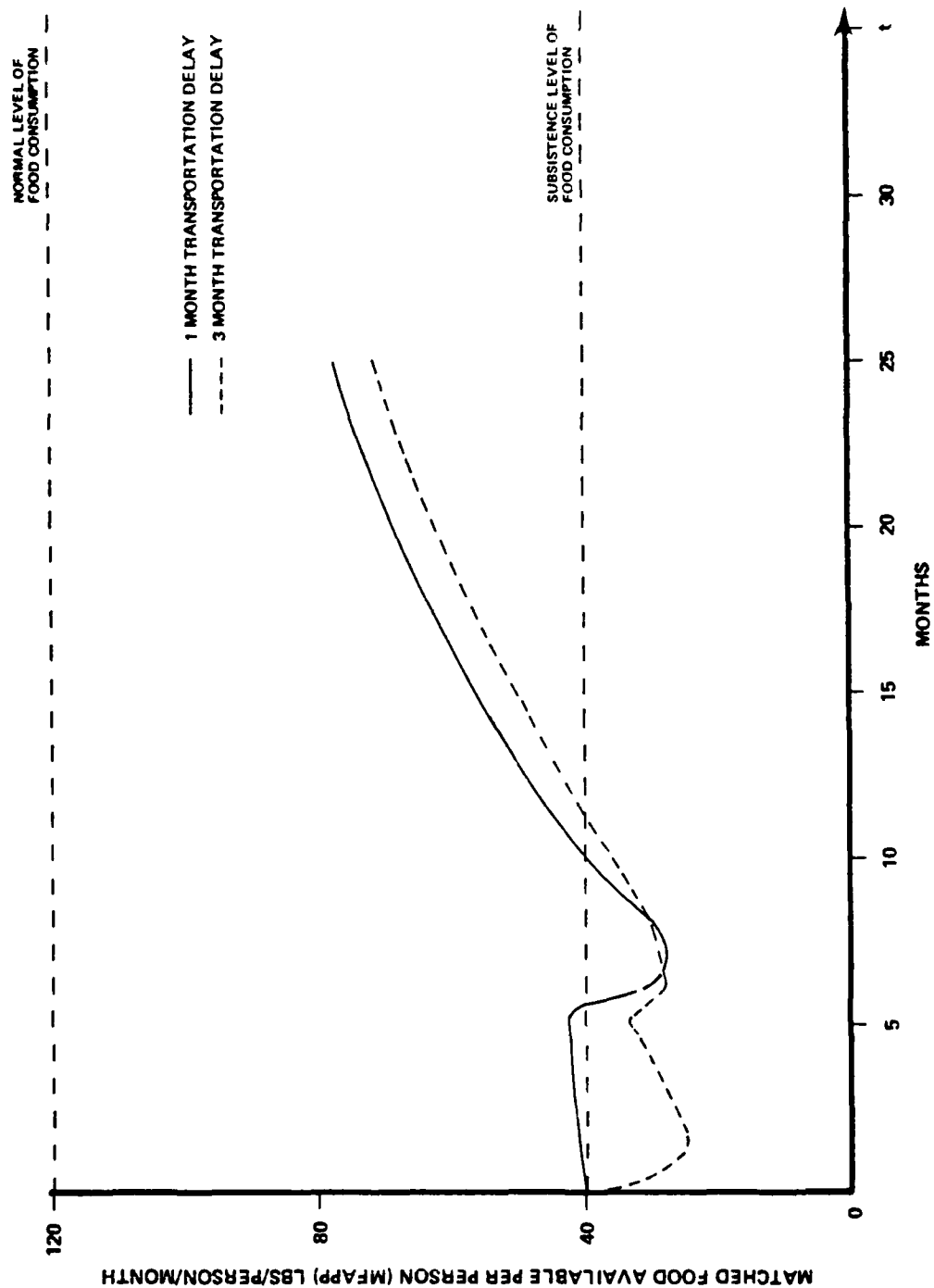
FIGURE 11

VIABILITY AND FOOD SUPPLY WITH TRANSPORTATION DELAY

(2 MONTH MATCHED FOOD SUPPLY ON HAND)
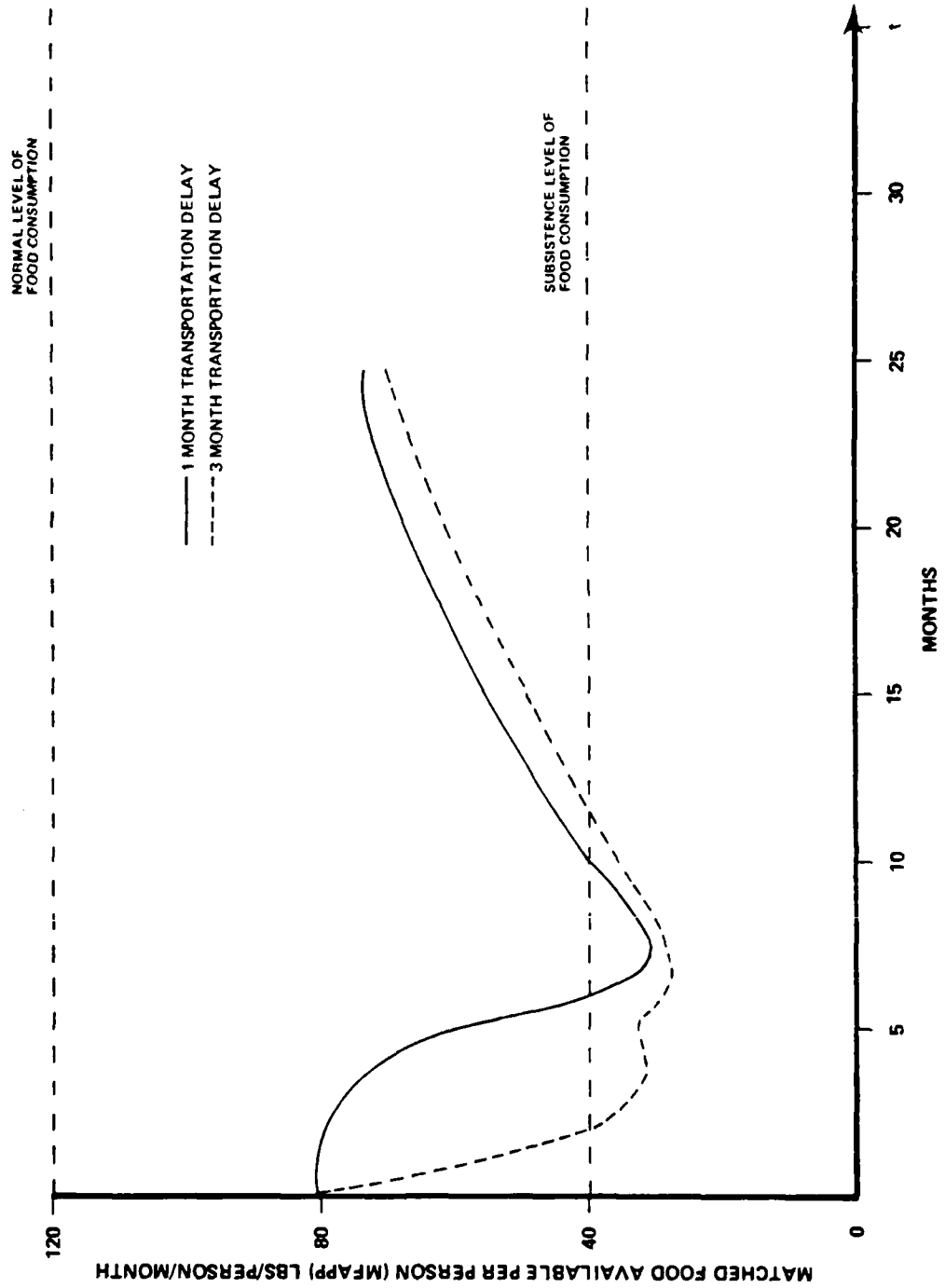
FIGURE 12

VIABILITY AND FOOD SUPPLY WITH TRANSPORTATION DELAY

(3 MONTH MATCHED FOOD SUPPLY ON HAND)
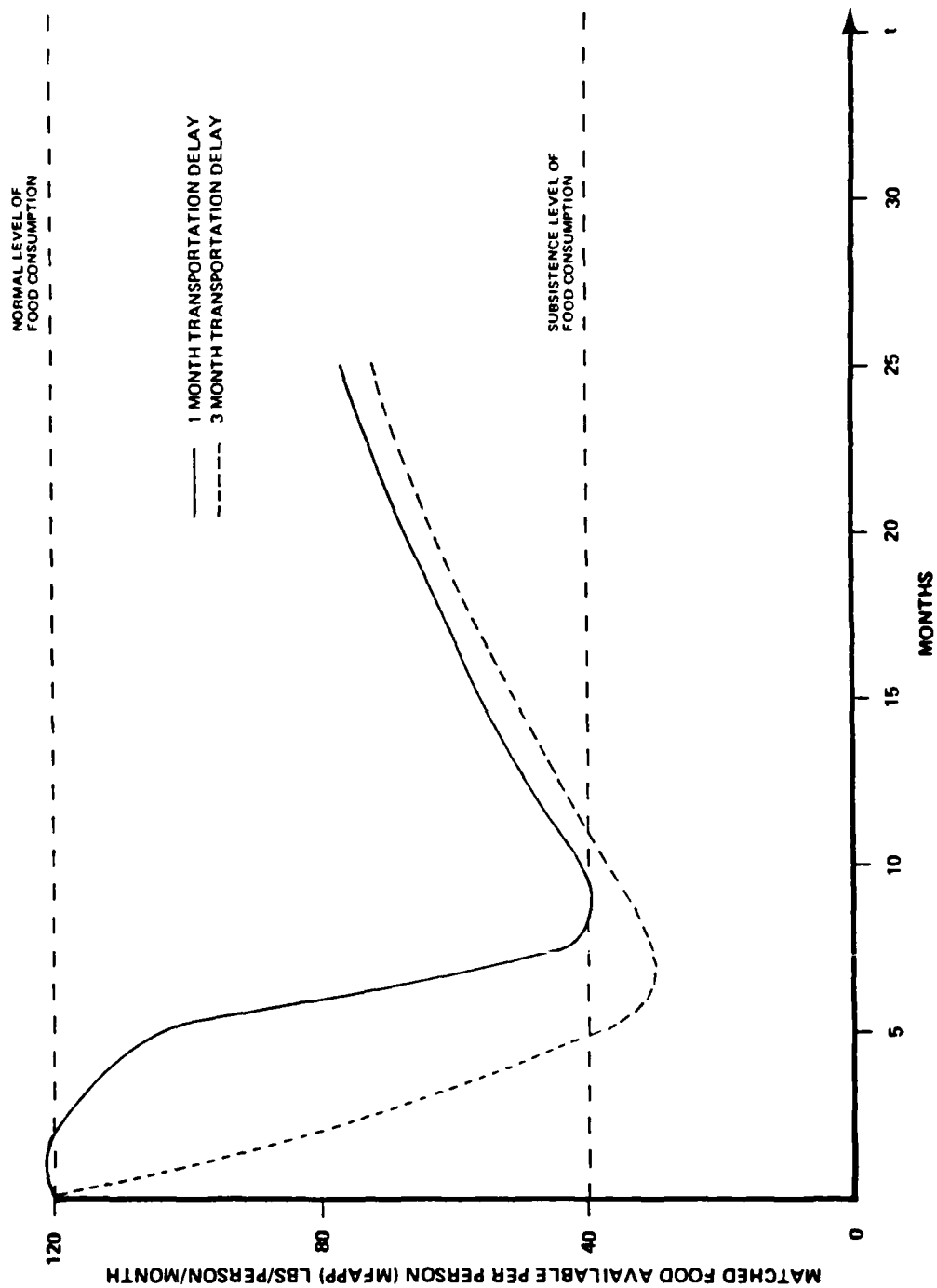
food availability is below the viability threshold level for approximately
ten months while the results displayed in Figure 12 show food availability
below the threshold for five months. Should one assume imminent collapse
in all three cases even though the trajectories reveal eventual recovery?
Clearly, the results in Figure 12 are more encouraging in terms of the
survivability of the system. The critical point, however, is that the
transportation delay is an important source of instability that threatens
viability. Moreover, instability is subject to control through effective
management policies and actions but only if managers are aware of its poten-
tial effects. In this sense, the PAM4 simulations offer an important contri-
bution.

Transportation delays represent only one of the potential sources of
instability in the system. Communication delays and delays in retraining
and transferring workers between sectors are two additional delay factors
that could affect the performance of the economy. Moreover, the economy
would be burdened with fixed requirements to support military and official
recovery operations. Again, the simulation results for PAM4 presented thus
far have not incorporated these factors as operating assumptions.

Figure 13 displays the results of a PAM4 simulation where these assump-
tions have been adopted. This simulation is based on the following initial
conditions: a three-month matched food supply, a 12-month food supply
inventory (not co-located with consumers), longer transportation and communi-
cation delays, increased worker retraining and allocation delays, and higher
fixed requirements on the economy. The solid curve depicts the economy's
performance with only the longer transportation delay assumed (from Figure 12).
The dashed curve displays the effects of the changes in the assumed initial
conditions. It is particularly interesting to note the downturn that occurs
later in the simulation period. Not only is the economy's performance de-
graded initially, the recovery seen in other simulations is never fully
achieved. Again, the importance of effective management policies to miti-
gate the effects of these delays is apparent.

FIGURE 13

VIABILITY AND FOOD SUPPLY WITH MULTIPLE DELAYS

(3 MONTH MATCHED FOOD SUPPLY ON HAND)
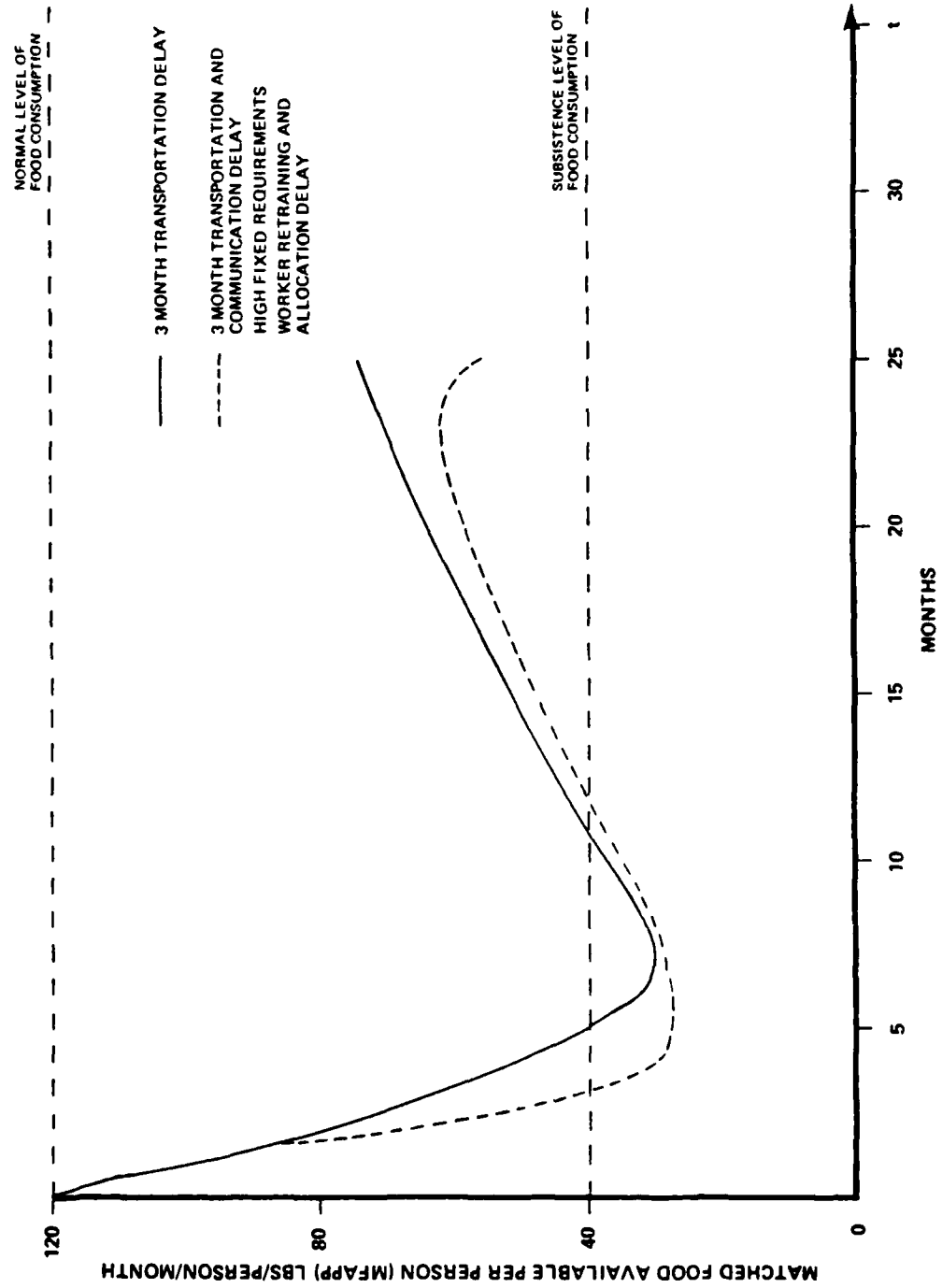
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VII. CONCLUSIONS

We noted at the outset of this study that our primary objective was
to determine if post-attack viability (or collapse) is automatic for a given
system, or if management actions could influence the outcome. In investi-
gating this problem our approach focused on exploring the structure of a
post-attack system for instabilities, identifying the processes that could
lead to collapse, and then evaluating if and how alternative post-attack
management policies could mitigate the effects of those instabilities.

At the conceptual level, our approach was to characterize a system's
post-attack viability in terms of an inventories "race." Since the immmediate
post-attack period would be marked by a reliance on stockpiles and inven-
tories to sustain the surviving population, the critical question was whether
inventories would be depleted before the economy could replenish supplies
by reorganizing initial production facilities. Moreover, we wanted to deter-
mine how various types of systemic instabilities would affect this inventories
race and how management actions could effectively overcome any debilitating
effects that these instabilities might have on the ability of the nation
to recover. These instabilities may appear due to the delays and uncertainties
affecting such basic economic support systems as communication and transpor-
tation networks, organizational structures and resource allocation mechanisms.

A system dynamics model was constructed of a post-attack economy to
study the management problems affecting these support systems in the imme-
diate post-attack period. Through repeated simulations, the model was able
to demonstrate the effects of potential instabilities on the performance of the
economy and how alternative management policies could mitigate those effects.
While the results should be qualified as being preliminary in the sense that
this effort is a first pass at the problem, there is sufficient evidence
to proceed with a more extended analysis The evidence suggests that the issue
of viability is greatly dependent on effective emergency preparedness policies
and resource management actions. The simulation results from the PAM4 model
clearly indicate that viability is not automatic even if adequate productive

productive capacities survive; the same system can produce both viability and collapse depending on the choice of policies and management strategies. If ineffective pre-attack and post-attack policies are followed, the potential for debilitating instabilities arising greatly increases and so, too, does the potential for system collapse.

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APPENDIX A

PAM4 COMPUTER PROGRAM

```
*******************************************************************
  INTERMEDIATE PRODUCTS SECTOR
*******************************************************************
```

IP.K=IP.J+(DT)(IPRR.JK-IPCR.JK-IPFRCR.JK)   1, L
IP=IPI   1.1, N
IPI=1000 UNITS   1.2, C
    IP   - INTERMEDIATE PRODUCTS (FUEL, TRUCKS,
                  TRACTORS, ETC.)
    IPRR   - INTERMEDIATE PRODUCTS REPLENISHMENT
                  (PRODUCTION) RATE
    IPCR   - INTERMEDIATE PRODUCTS CONSUMPTION RATE
    IPFRCR - FIXED REQUIREMENTS CONSUMPTION (OUT
                  SHIPMENT) RATE
    IPI   - NUMBER OF IP UNITS IN SYSTEM INITIALLY

IPFRCR.KL=MIN(IPFROR.JK,IP.K)   2, R
    IPFRCR - FIXED REQUIREMENTS CONSUMPTION (OUT
                  SHIPMENT) RATE
    IPFROR - FIXED EXTERNAL REQUIREMENT ORDERS LEVIED ON
                  IP PRODUCT SUPPLIES
    IP   - INTERMEDIATE PRODUCTS (FUEL, TRUCKS,
                  TRACTORS, ETC.)

IPCR.KL=MAX(0,MIN(IP.K-IPFRCR.JK,IPB.K-IPFROR.JK)) 3, R
    IPCR   - INTERMEDIATE PRODUCTS CONSUMPTION RATE
    IP   - INTERMEDIATE PRODUCTS (FUEL, TRUCKS,
                  TRACTORS, ETC.)
    IPFRCR - FIXED REQUIREMENTS CONSUMPTION (OUT
                  SHIPMENT) RATE
    IPB   - THE BACKORDERS (BACKLOG) FOR INTERMEDIATE
                  PRODUCTS
    IPFROR - FIXED EXTERNAL REQUIREMENT ORDERS LEVIED ON
                  IP PRODUCT SUPPLIES

IPRR.KL=IPP.K/PRODD.K   4, R
    IPRR   - INTERMEDIATE PRODUCTS REPLENISHMENT
                  (PRODUCTION) RATE
    IPP   - INTERMEDIATE PRODUCTS IN THE PRODUCTION
                  PIPELINE NOT YET RECEIVED
    PRODD   - PRODUCTION DELAY FOR INTERMEDIATE PRODUCTS

PRODD.K=PRODLY+CPDM.K   5, A
PRODLY=2 MONTHS   5.1, C
    PRODD   - PRODUCTION DELAY FOR INTERMEDIATE PRODUCTS
    PRODLY - THE MINIMUM IP PRODUCTION DELAY DUE TO
                  PURELY PHYSICAL LIMITS
    CPDM   - THE DELAY IN IP PRODUCTION DUE TO SHORTAGE
                  OF CAPITAL PLANT

CPDM.K=TABHL(CPDMT,IC.K/C.K,0,1,.2)   6, A
CPDMT=0/.2/.5/1.0/2.0   6.1, T
    CPDM   - THE DELAY IN IP PRODUCTION DUE TO SHORTAGE
                  OF CAPITAL PLANT
    CPDMT   - TABLE FOR IP PRODUCTION DELAY VALUES
    C   - CAPITAL PLANT AND EQUIPMENT
```

```
IPB.K=IPB.J+(DT)(IPORR.JK+IPFROR.JK-IPFRCR.JK-        7, L
   IPCR.JK)
IPB=IPBI                                               7.1, N
IPBI=1000 UNITS                                        7.2, C
       IPB    - THE BACKORDERS (BACKLOG) FOR INTERMEDIATE
                   PRODUCTS
       IPORR  - THE ORDER RECEIVING RATE FOR INTERMEDIATE
                   PRODUCTS (DEMAND)
       IPFROR - FIXED EXTERNAL REQUIREMENT ORDERS LEVIED ON
                   IP PRODUCT SUPPLIES
       IPFRCR - FIXED REQUIREMENTS CONSUMPTION (OUT
                   SHIPMENT) RATE
       IPCR   - INTERMEDIATE PRODUCTS CONSUMPTION RATE
       IPBI   - NUMBER OF IP BACKORDERS INITIALLY


IPFROR.KL=FRIP*IP.K                                    8, R
FRIP=.10 PERCENT                                       8.1, C
       IPFROR - FIXED EXTERNAL REQUIREMENT ORDERS LEVIED ON
                   IP PRODUCT SUPPLIES
       FRIP   - PERCENT OF IP SUPPLIES THAT ARE
                   REQUISITIONED FROM OUTSIDE
       IP     - INTERMEDIATE PRODUCTS (FUEL, TRUCKS,
                   TRACTORS, ETC.)


IPORR.KL=IPCINF.K+IPCINT.K                             9, R
       IPORR  - THE ORDER RECEIVING RATE FOR INTERMEDIATE
                   PRODUCTS (DEMAND)
       IPCINF - INTERMEDIATE PRODUCTS CONSUMED IN FOOD
                   PRODUCTION
       IPCINT - INTERMEDIATE PRODUCTS CONSUMED IN FOOD
                   TRANSPORTATION


NETIPS.K=MAX(0,IPB.K-IP.K)                             10, A
       NETIPS - THE NET IP SUPPLIES ON HAND ( BACKORDERS
                   COMPARED WITH SUPPLY)
       IPB    - THE BACKORDERS (BACKLOG) FOR INTERMEDIATE
                   PRODUCTS
       IP     - INTERMEDIATE PRODUCTS (FUEL, TRUCKS,
                   TRACTORS, ETC.)


IPP.K=IPP.J+(DT)(IPOR.JK-IPRR.JK)                      11, L
IPP=IPPI                                               11.1, N
IPPI=800 UNITS                                         11.2, C
       IPP    - INTERMEDIATE PRODUCTS IN THE PRODUCTION
                   PIPELINE NOT YET RECEIVED
       IPOR   - RATE AT WHICH INTERMEDIATE PRODUCTS ARE
                   ORDERED INTO PRODUCTION
       IPRR   - INTERMEDIATE PRODUCTS REPLENISHMENT
                   (PRODUCTION) RATE
```

```
DIPP.K=(MAX(0,NETIPS.K-IPP.K))*C200              12, A
C200=1.0                                         12.1, C
     DIPP    - DESIRED INTERMEDIATE PRODUCTION RATE (NET
                  SUPPLIES - PIPELINE)
     NETIPS  - THE NET IP SUPPLIES ON HAND ( BACKORDERS
                  COMPARED WITH SUPPLY)
     IPP     - INTERMEDIATE PRODUCTS IN THE PRODUCTION
                  PIPELINE NOT YET RECEIVED
     C200    - PERCENT OF IP SUPPLY DISCREPANCY BETWEEN
                  ORDERED AND DESIRED

IPWD.K=DIPP.K/IPPPW.K                            13, A
     IPWD    - DEMAND FOR IP PRODUCTION WORKERS
     DIPP    - DESIRED INTERMEDIATE PRODUCTION RATE (NET
                  SUPPLIES - PIPELINE)
     IPPPW   - PRODUCTIVITY PER INTERMEDIATE PRODUCTS
                  WORKER

IPPPW.K=IPPWN*IPPM.K                             14, A
     IPPPW   - PRODUCTIVITY PER INTERMEDIATE PRODUCTS
                  WORKER
     IPPWN   - NORMAL PRODUCTIVITY PER IP WORKER
     IPPM    - IP WORKER PRODUCTIVITY MULTIPLIER (HEALTH
                  AND FOOD SHORTAGES)

IPPM.K=TABHL(IPPMT,FSHORT.K,0,1,.2)              15, A
IPPMT=1/.9/.6/.4/.2/0                            15.1, T
IPPWN=1                                          15.2, C
     IPPM    - IP WORKER PRODUCTIVITY MULTIPLIER (HEALTH
                  AND FOOD SHORTAGES)
     IPPMT   - TABLE FOR IP WORKER PRODUCTIVITY VALUES
     IPPWN   - NORMAL PRODUCTIVITY PER IP WORKER

IPW.K=IPW.J+(DT)(IPWINR.JK-IPWOUT.JK)            16, L
IPW=IPWI                                         16.1, N
IPWI=1000 WORKERS                                16.2, C
     IPW     - THE INTERMEDIATE PRODUCTS WORKERS
     IPWINR  - RATE OF WORKERS ENTERING IP SECTOR
     IPWOUT  - RATE AT WHICH WORKERS LEAVE IP SECTOR
     IPWI    - NUMBER OF IP WORKERS IN SYSTEM INITIALLY

IPOR.KL=MIN(DIPP.K,IPW.K*IPPPW.K)                17, R
     IPOR    - RATE AT WHICH INTERMEDIATE PRODUCTS ARE
                  ORDERED INTO PRODUCTION
     DIPP    - DESIRED INTERMEDIATE PRODUCTION RATE (NET
                  SUPPLIES - PIPELINE)
     IPW     - THE INTERMEDIATE PRODUCTS WORKERS
     IPPPW   - PRODUCTIVITY PER INTERMEDIATE PRODUCTS
                  WORKER

IPWINR.KL=CLIP(IPWINA.K,0,DISIPW.K,0)            18, R
     IPWINR  - RATE OF WORKERS ENTERING IP SECTOR
     IPWINA  - CALCULATION FOR WORKERS ENTERING IP SECTOR
     DISIPW  - DISCREPANCY BETWEEN DESIRED AND ACTUAL
                  NUMBER OF IP WORKERS
```

```
IPWINA.K=MAX(0,WP.K*PDIPW.K*IPWDF)                      19, A
IPWDF=.8                                                19.1, C
     IPWINA  - CALCULATION FOR WORKERS ENTERING IP SECTOR
     WP      - POOL OF WORKERS IN THE SYSTEM NOT EMPLOYED
     PDIPW   - PERCENT OF IP WORKERS DESIRED
     IPWDF   - DELAY FACTOR FOR TRANSFERRING WORKERS TO IP
               SECTOR


DISIPW.K=DIPW.K-IPW.K                                   20, A
     DISIPW  - DISCREPANCY BETWEEN DESIRED AND ACTUAL
               NUMBER OF IP WORKERS
     DIPW    - DESIRED NUMBER OF IP WORKERS
     IPW     - THE INTERMEDIATE PRODUCTS WORKERS


DIPW.K=PDIPW.K*WA.K                                     21, A
     DIPW    - DESIRED NUMBER OF IP WORKERS
     PDIPW   - PERCENT OF IP WORKERS DESIRED
     WA      - TOTAL NUMBER OF WORKERS AVAILABLE IN THE
               SYSTEM


PDIPW.K=IPWD.K/(IPWD.K+CWD.K+FTWD.K+FSWD.K)             22, A
     PDIPW   - PERCENT OF IP WORKERS DESIRED
     IPWD    - DEMAND FOR IP PRODUCTION WORKERS
     CWD     - DEMAND FOR CAPITAL WORKERS
     FTWD    - DEMAND FOR FOOD TRANSPORTATION WORKERS
     FSWD    - DEMAND FOR FOOD SUPPLY WORKERS


WA.K=IPW.K+CW.K+FTW.K+FSW.K+WP.K                        23, A
     WA      - TOTAL NUMBER OF WORKERS AVAILABLE IN THE
               SYSTEM
     IPW     - THE INTERMEDIATE PRODUCTS WORKERS
     CW      - THE CAPITAL SECTOR WORKERS
     FTW     - THE FOOD TRANSPORT WORKERS
     FSW     - THE FOOD SUPPLY WORKERS
     WP      - POOL OF WORKERS IN THE SYSTEM NOT EMPLOYED


IPWOUT.KL=CLIP(0,IPWOUA.K,DISIPW.K,0)                   24, R
     IPWOUT  - RATE AT WHICH WORKERS LEAVE IP SECTOR
     IPWOUA  - CALCULATION FOR WORKERS LEAVING IP SECTOR
     DISIPW  - DISCREPANCY BETWEEN DESIRED AND ACTUAL
               NUMBER OF IP WORKERS


IPWOUA.K=-DISIPW.K*IPWDF                                25, A
     IPWOUA  - CALCULATION FOR WORKERS LEAVING IP SECTOR
     DISIPW  - DISCREPANCY BETWEEN DESIRED AND ACTUAL
               NUMBER OF IP WORKERS
     IPWDF   - DELAY FACTOR FOR TRANSFERRING WORKERS TO IP
               SECTOR
```

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**********************************************************
         CAPITAL SECTOR  (PLANT AND EQUIPMENT)
**********************************************************
```

C.K=C.J+(DT)(CCRD.JK-COR.JK-CFR.JK)   26, L
C=CI   26.1, N
CI=200 UNITS   26.2, C

    C   - CAPITAL (PLANT AND EQUIPMENT)
    CCRD   - RATE OF CAPITAL CONSTRUCTION (DELAYED)
    COR   - RATE AT WHICH CAPITAL BECOMES OBSOLESCENT
    CFR   - FIXED REQUIREMENTS CONSUMPTION (OUT
              SHIPMENT) RATE
    CI   - NUMBER OF CAPITAL UNITS IN THE SYSTEM
              INITIALLY

CFR.KL=MAX(0,MIN(C.K,CFIX))*SWITCH.K   27, R
CFIX=20 UNITS   27.1, C

    CFR   - FIXED REQUIREMENTS CONSUMPTION (OUT
              SHIPMENT) RATE
    C   - CAPITAL (PLANT AND EQUIPMENT)
    CFIX   - AMOUNT OF CAPITAL REQUISITIONED FROM
              OUTSIDE
    SWITCH - TIME DELAY AFFECTING FIXED REQUIREMENTS FOR
              CAPITAL

CIP.K=CIP.J+(DT)(CCR.JK-CCRD.JK)   28, L
CIP=CIPI   28.1, N
CIPI=0   28.2, C

    CIP   - AMOUNT OF CAPITAL IN CONSTRUCTION
    CCR   - CAPITAL CONSTRUCTION RATE
    CCRD   - RATE OF CAPITAL CONSTRUCTION (DELAYED)
    CIPI   - AMOUNT OF CAPITAL CONSTRUCTION IN THE
              SYSTEM INITIALLY

EFFCAP.K=C.K+CIP.K   29, A

    EFFCAP - EFFECTIVE AMOUNT OF CAPITAL (PIPELINE +
              ACTUAL)
    C   - CAPITAL (PLANT AND EQUIPMENT)
    CIP   - AMOUNT OF CAPITAL IN CONSTRUCTION

SWITCH.K=STEP(1,TIM)   30, A
TIM=10   30.1, C

    SWITCH - TIME DELAY AFFECTING FIXED REQUIREMENTS FOR
              CAPITAL
    TIM   - TIME WHEN FIXED REQUIREMENTS FOR CAPITAL
              ENTER SYSTEM

COR.KL=CORF*C.K   31, R
CORF=.06 PERCENT   31.1, C

    COR   - RATE AT WHICH CAPITAL BECOMES OBSOLESCENT
    CORF   - PERCENT CAPITAL OBSOLESCENT FACTOR
    C   - CAPITAL (PLANT AND EQUIPMENT)

```
CCRD.KL=CIP.K/CCRDF                               32, R
CCRDF=6 MONTHS                                    32.1, C
     CCRD   - RATE OF CAPITAL CONSTRUCTION (DELAYED)
     CIP    - AMOUNT OF CAPITAL IN CONSTRUCTION
     CCRDF  - DELAY FACTOR IN CAPITAL CONSTRUCTION RATE


CCR.KL=MIN(DCC.K,CW.K*PRODC.K)                     33, R
     CCR    - CAPITAL CONSTRUCTION RATE
     DCC    - DESIRED RATE FOR CAPITAL CONSTRUCTION
     CW     - THE CAPITAL SECTOR WORKERS
     PRODC  - PRODUCTIVITY OF CAPITAL WORKERS


DCC.K=MAX(0,CD.K)                                  34, A
     DCC    - DESIRED RATE FOR CAPITAL CONSTRUCTION
     CD     - DISCREPANCY IN CAPITAL PLANT AND EQUIPMENT
                 (DESIRED - EFFECTIVE)


CD.K=(DC.K-EFFCAP.K)*POLICY                         35, A
     CD     - DISCREPANCY IN CAPITAL PLANT AND EQUIPMENT
                 (DESIRED - EFFECTIVE)
     EFFCAP - EFFECTIVE AMOUNT OF CAPITAL (PIPELINE +
                 ACTUAL)
     POLICY - PRODUCTION LEVEL DESIRED BY POLICYMAKER


DC.K=IPOR.JK*CRPUIP                                36, A
CRPUIP=1                                           36.1, C
POLICY=1.0                                         36.2, C
     IPOR   - RATE AT WHICH INTERMEDIATE PRODUCTS ARE
                 ORDERED INTO PRODUCTION
     CRPUIP - CAPITAL TO INTERMEDIATE PRODUCT  PRODUCTION
                 RATIO REQUIRED
     POLICY - PRODUCTION LEVEL DESIRED BY POLICYMAKER


PRODC.K=CCPWN*CWPM.K                               37, A
CCPWN=.06 PRODUCTIVITY                             37.1, C
     PRODC  - PRODUCTIVITY OF CAPITAL WORKERS
     CCPWN  - NORMAL PRODUCTIVTY FACTOR
     CWPM   - CAPITAL WORKER PRODUCTIVITY MULTIPLIER
                 (HEALTH AND FOOD SHORTAGES)


CWPM.K=TABHL(CWPMT,FSHORT.K,0,1,.2)               38, A
CWPMT=1/.9/.6/.4/.2/0                              38.1, T
     CWPM   - CAPITAL WORKER PRODUCTIVITY MULTIPLIER
                 (HEALTH AND FOOD SHORTAGES)
     CWPMT  - TABLE FOR CAPITAL WORKER PRODUCTIVITY
                 VALUES


CW.K=CW.JH(DT)(CWTNR.JK-CWOUTR.JK)                39, L
CW=CWI                                             39.1, N
CWI=1000 OF                                        39.2, C
     CW     - THE CAPITAL SECTOR WORKERS
     CWTNR  - RATE OF WORKERS ENTERING CAPITAL SECTOR
     CWOUTR - RATE AT WHICH WORKERS LEAVE CAPITAL SECTOR
     CWI    - NUMBER OF WORKERS IN CAPITAL SECTOR
                 INITIALLY
```

```
CWINR.KL=CLIP(CWINA.K,0,DISCCW.K,0)                    40, R
    CWINR  - RATE OF WORKERS ENTERING CAPITAL SECTOR
    CWINA  - CALCULATION FOR WORKERS ENTERING CAPITAL
             SECTOR
    DISCCW - DISCREPANCY BETWEEN DESIRED AND ACTUAL
             NUMBER OF CAPITAL WORKERS

CWINA.K=MAX(0,WP.K*PDCW.K*CWDF)                        41, A
CWDF=.8                                                41.1, C
    CWINA  - CALCULATION FOR WORKERS ENTERING CAPITAL
             SECTOR
    WP     - POOL OF WORKERS IN THE SYSTEM NOT EMPLOYED
    PDCW   - PERCENT OF CAPITAL WORKERS DESIRED
    CWDF   - DELAY FACTOR FOR TRANSFERRING WORKERS TO
             CAPITAL SECTOR

DISCCW.K=DCW.K-CW.K                                    42, A
    DISCCW - DISCREPANCY BETWEEN DESIRED AND ACTUAL
             NUMBER OF CAPITAL WORKERS
    DCW    - DESIRED NUMBER OF CAPITAL WORKERS
    CW     - THE CAPITAL SECTOR WORKERS

DCW.K=PDCW.K*WA.K                                      43, A
    DCW    - DESIRED NUMBER OF CAPITAL WORKERS
    PDCW   - PERCENT OF CAPITAL WORKERS DESIRED
    WA     - TOTAL NUMBER OF WORKERS AVAILABLE IN THE
             SYSTEM

PDCW.K=CWD.K/(IPWD.K+CWD.K+FTWD.K+FSWD.K)              44, A
    PDCW   - PERCENT OF CAPITAL WORKERS DESIRED
    CWD    - DEMAND FOR CAPITAL WORKERS
    IPWD   - DEMAND FOR IP PRODUCTION WORKERS
    FTWD   - DEMAND FOR FOOD TRANSPORTATION WORKERS
    FSWD   - DEMAND FOR FOOD SUPPLY WORKERS

CWOUTR.KL=CLIP(0,CWOUT.K,DISCCW.K,0)                   45, R
    CWOUTR - RATE AT WHICH WORKERS LEAVE CAPITAL SECTOR
    CWOUT  - CALCULATION FOR WORKERS LEAVING CAPITAL
             SECTOR
    DISCCW - DISCREPANCY BETWEEN DESIRED AND ACTUAL
             NUMBER OF CAPITAL WORKERS

CWOUT.K=-DISCCW.K*CWDF                                 46, A
    CWOUT  - CALCULATION FOR WORKERS LEAVING CAPITAL
             SECTOR
    DISCCW - DISCREPANCY BETWEEN DESIRED AND ACTUAL
             NUMBER OF CAPITAL WORKERS
    CWDF   - DELAY FACTOR FOR TRANSFERRING WORKERS TO
             CAPITAL SECTOR

CWD.K=DCC.K/PRODC.K                                    47, A
    CWD    - DEMAND FOR CAPITAL WORKERS
    DCC    - DESIRED RATE FOR CAPITAL CONSTRUCTION
    PRODC  - PRODUCTIVITY OF CAPITAL WORKERS
```

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*****************************************************
        FOOD SUPPLY SECTOR
*****************************************************
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FS.K=FS.J+(DT)(FRR.JK-FFRSR.JK-FSR.JK)   48, L
FS=FSI   48.1, N
FSI=440E3   48.2, C
     FS   - FOOD SUPPLY AT THE PRODUCTION SITES
     FRR   - RATE AT WHICH FOOD IS RECEIVED FROM
              PRODUCTION SOURCES
     FFRSR - RATE AT WHICH FOOD IS SHIPPED TO MEET FIXED
              REQUIREMENTS
     FSR   - RATE AT WHICH FOOD IS SHIPPED
     FSI   - AMOUNT OF FOOD SUPPLY AT PRODUCTION SITES
              INITIALLY

FFRSR.KL=MIN(FFROR.JK,FS.K)   49, R
     FFRSR - RATE AT WHICH FOOD IS SHIPPED TO MEET FIXED
              REQUIREMENTS
     FFROR - RATE OF FOOD SUPPLY REQUISITIONED FROM
              OUTSIDE
     FS   - FOOD SUPPLY AT THE PRODUCTION SITES

FFROR.KL=FSFIX   50, R
FSFIX=44E3 LBS   50.1, C
     FFROR - RATE OF FOOD SUPPLY REQUISITIONED FROM
              OUTSIDE
     FSFIX - AMOUNT OF FOOD SUPPLY REQUISITIONED FROM
              OUTSIDE

FRR.KL=FOODIP.K/FPD.K   51, R
     FRR   - RATE AT WHICH FOOD IS RECEIVED FROM
              PRODUCTION SOURCES
     FOODIP - FOOD IN PRODUCTION AT THE FOOD SUPPLY SITES
     FPD   - TOTAL DELAY FOR FOOD PRODUCTION

FPD.K=PD+IPFPD.K   52, A
PD=3 MONTH   52.1, C
     FPD   - TOTAL DELAY FOR FOOD PRODUCTION
     PD   - DELAY IN PRODUCING FOOD
     IPFPD - THE DELAYS IN FOOD PRODUCTION DUE TO IP
              SUPPLIES

IPFPD.K=CLIP(0,4,IP.K-IPB.K,0)   53, A
     IPFPD - THE DELAYS IN FOOD PRODUCTION DUE TO IP
              SUPPLIES
     IP   - INTERMEDIATE PRODUCTS (FUEL, TRUCKS,
              TRACTORS, ETC.)
     IPB   - THE BACKORDERS (BACKLOG) FOR INTERMEDIATE
              PRODUCTS

FSR.KL=MIN(DFSR.K,FSXPW.K*FTW.K)   54, R
     FSR   - RATE AT WHICH FOOD IS SHIPPED
     DFSR   - DESIRED RATE OF FOOD SHIPMENT
     FSXPW - AMOUNT OF FOOD TRANSPORTED PER WORKER
     FTW   - THE FOOD TRANSPORT WORKERS

```
DFSR.K=MAX(O,MIN(FSB.K-FFROR.JK,FS.K-FFRSR.JK))        55, A
    DFSR    - DESIRED RATE OF FOOD SHIPMENT
    FSB     - BACKORDERS FOR FOOD AT THE FOOD SUPPLY
                 SITES
    FFROR   - RATE OF FOOD SUPPLY REQUISITIONED FROM
                 OUTSIDE
    FS      - FOOD SUPPLY AT THE PRODUCTION SITES
    FFRSR   - RATE AT WHICH FOOD IS SHIPPED TO MEET FIXED
                 REQUIREMENTS


FSXPW.K=FSXPWN*FSXPM.K                                 56, A
FSXPWN=1220 LBS                                        56.1, C
    FSXPW   - AMOUNT OF FOOD TRANSPORTED PER WORKER
    FSXPWN  - AMOUNT OF FOOD TRANSPORTED PER WORKER
                 (NORMALLY)
    FSXPM   - FOOD TRANSPORTATION MULTIPLIER (HEALTH &
                 FOOD SHORTAGES)


FSXPM.K=TABHL(FSXPMT,FSHORT.K,0,1,.2)                  57, A
FSXPMT=1/.9/.6/.4/.2/0                                 57.1, T
    FSXPM   - FOOD TRANSPORTATION MULTIPLIER (HEALTH &
                 FOOD SHORTAGES)
    FSXPMT  - TABLE FOR FOOD TRANSPORTATION MULTIPLIER
                 VALUES


FTW.K=FTW.J+(DT)(FTWINR.JK-FTWOUT.JK)                  58, L
FTW=FTWI                                               58.1, N
FTWI=1000 FOOD                                         58.2, C
    FTW     - THE FOOD TRANSPORT WORKERS
    FTWINR  - RATE OF WORKERS ENTERING FOOD
                 TRANSPORTATION SECTOR
    FTWOUT  - RATE AT WHICH WORKERS LEAVE FOOD
                 TRANSPORTATION SECTOR
    FTWI    - NUMBER OF WORKERS IN FOOD TRANSPORTATION
                 INITIALLY


FTWINR.KL=CLIP(FTWINA.K,0,DISFTW.K,0)                  59, R
    FTWINR  - RATE OF WORKERS ENTERING FOOD
                 TRANSPORTATION SECTOR
    FTWINA  - CALCULATION FOR WORKERS ENTERING FOOD
                 TRANSPORTATION SECTOR
    DISFTW  - DISCREPANCY BETWEEN DESIRED & ACTUAL FOOD
                 TRANSPORTATION WORKERS


FTWINA.K=MAX(O,WP.K*PDFTW.K*FTWDF)                     60, A
FTWDF=.8                                               60.1, C
    FTWINA  - CALCULATION FOR WORKERS ENTERING FOOD
                 TRANSPORTATION SECTOR
    WP      - POOL OF WORKERS IN THE SYSTEM NOT EMPLOYED
    FTWDF   - DELAY FACTOR TO TRANSFER WORKERS TO FOOD
                 TRANSPORTATION SECTOR
```

```
DISFTW.K=DFTW.K-FTW.K                                         61, A
     DISFTW - DISCREPANCY BETWEEN DESIRED & ACTUAL FOOD
                 TRANSPORTATION WORKERS
     DFTW   - DESIRED NUMBER OF FOOD TRANSPORTATION
                 WORKERS
     FTW    - THE FOOD TRANSPORT WORKERS

DFTW.K=PDFTW.K*WA.K                                           62, A
     DFTW   - DESIRED NUMBER OF FOOD TRANSPORTATION
                 WORKERS
     WA     - TOTAL NUMBER OF WORKERS AVAILABLE IN THE
                 SYSTEM

PDFTW.K=FTWD.K/(IPWD.K+CWD.K+FTWD.K+FSWD.K)                   63, A
     FTWD   - DEMAND FOR FOOD TRANSPORTATION WORKERS
     IPWD   - DEMAND FOR IP PRODUCTION WORKERS
     CWD    - DEMAND FOR CAPITAL WORKERS
     FSWD   - DEMAND FOR FOOD SUPPLY WORKERS

FTWOUT.KL=CLIP(0,FTWOUA.K,DISFTW.K,0)                         64, R
     FTWOUT - RATE AT WHICH WORKERS LEAVE FOOD
                 TRANSPORTATION SECTOR
     FTWOUA - CALCULATION FOR WORKERS LEAVING FOOD
                 TRANSPORTATION SECTOR
     DISFTW - DISCREPANCY BETWEEN DESIRED & ACTUAL FOOD
                 TRANSPORTATION WORKERS

FTWOUA.K=-DISFTW.K*FTWDF                                      65, A
     FTWOUA - CALCULATION FOR WORKERS LEAVING FOOD
                 TRANSPORTATION SECTOR
     DISFTW - DISCREPANCY BETWEEN DESIRED & ACTUAL FOOD
                 TRANSPORTATION WORKERS
     FTWDF  - DELAY FACTOR TO TRANSFER WORKERS TO FOOD
                 TRANSPORTATION SECTOR

FTWD.K=DFSR.K/FSXPW.K                                         66, A
     FTWD   - DEMAND FOR FOOD TRANSPORTATION WORKERS
     DFSR   - DESIRED RATE OF FOOD SHIPMENT
     FSXPW  - AMOUNT OF FOOD TRANSPORTED PER WORKER

FSB.K=FSB.J+(DT)(FSORR.JK+FFROR.JK-FFRSR.JK-FSR.JK) 67, L
     FSB    - BACKORDERS FOR FOOD AT THE FOOD SUPPLY
                 SITES
     FSORR  - RATE AT WHICH FOOD SUPPLY ORDERS ARE
                 RECEIVED
     FFROR  - RATE OF FOOD SUPPLY REQUISITIONED FROM
                 OUTSIDE
     FFRSR  - RATE AT WHICH FOOD IS SHIPPED TO MEET FIXED
                 REQUIREMENTS
     FSR    - RATE AT WHICH FOOD IS SHIPPED
```

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FSORR.KL=DELAY3(MFSOR.JK,COMMD)                      68, R
COMMD=1 MONTH                                        68.1, C
FSB=FSBI                                             68.2, N
FSBI=440E3 LBS                                       68.3, C
        FSORR   - RATE AT WHICH FOOD SUPPLY ORDERS ARE
                    RECEIVED
        MFSOR   - MATCHED FOOD SUPPLY ORDER RATE
        COMMD   - COMMUNICATION DELAY AFFECTING FOOD ORDERS
        FSB     - BACKORDERS FOR FOOD AT THE FOOD SUPPLY
                    SITES
        FSBI    - BACKORDERS FOR FOOD AT FOOD SUPPLY SITES
                    INITIALLY


NETFS.K=MAX(0,FSB.K-FS.K)                            69, A
        NETFS   - NET FOOD SUPPLY (BACKORDERS COMPARED TO
                    SUPPLY)
        FSB     - BACKORDERS FOR FOOD AT THE FOOD SUPPLY
                    SITES
        FS      - FOOD SUPPLY AT THE PRODUCTION SITES


FOODIP.K=FOODIP.J+(DT)(FPR.JK-FRR.JK)               70, L
FOODIP=FIPI                                          70.1, N
FIPI=1260E3                                          70.2, C
        FOODIP  - FOOD IN PRODUCTION AT THE FOOD SUPPLY SITES
        FPR     - RATE AT WHICH FOOD IS PRODUCED
        FRR     - RATE AT WHICH FOOD IS RECEIVED FROM
                    PRODUCTION SOURCES
        FIPI    - FOOD IN PRODUCTION AT SUPPLY SITES
                    INITIALLY


FPR.KL=MIN(DFP.K,FSW.K*FPFSWN*FSWPM.K)              71, R
FSFPW.K=FPFSWN*FSWPM.K                               71.1, A
        FPR     - RATE AT WHICH FOOD IS PRODUCED
        DFP     - DESIRED LEVEL OF FOOD PRODUCTION
        FSW     - THE FOOD SUPPLY WORKERS
        FPFSWN  - AMOUNT OF FOOD PRODUCED PER FOOD SUPPLY
                    WORKER NORMALLY
        FSWPM   - FOOD SUPPLY WORKER PRODUCTIVITY  (HEALTH
                    AND FOOD SHORTAGES)
        FSFPW   - AMOUNT OF FOOD SUPPLY PRODUCED PER WORKER


DFP.K=MAX(0,NETFS.K-FOODIP.K)*C201                  72, A
C201=1.0                                             72.1, C
FPFSWN=1680 LBS                                      72.2, C
        DFP     - DESIRED LEVEL OF FOOD PRODUCTION
        NETFS   - NET FOOD SUPPLY (BACKORDERS COMPARED TO
                    SUPPLY)
        FOODIP  - FOOD IN PRODUCTION AT THE FOOD SUPPLY SITES
        C201    - PERCENT OF FOOD IN PRODUCTION DESIRED
        FPFSWN  - AMOUNT OF FOOD PRODUCED PER FOOD SUPPLY
                    WORKER NORMALLY
```

```
FSWPM.K=TABHL(FSWPMT,FSHORT.K,0,1,.2)              73, A
FSWPMT=1/.9/.6/.4/.2/0                             73.1, T
     FSWPM   - FOOD SUPPLY WORKER PRODUCTIVITY  (HEALTH
                   AND FOOD SHORTAGES)
     FSWPMT  - TABLE FOR FOOD SUPPLY WORKER PRODUCTIVITY
                   MULTIPLIER VALUES


FSW.K=FSW.J+(DT)(FSWINR.JK-FSWOUT.JK)              74, L
FSW=FSWI                                           74.1, N
FSWI=1000 INITIAL                                  74.2, C
     FSW     - THE FOOD SUPPLY WORKERS
     FSWINR  - RATE AT WHICH WORKERS ENTER FOOD PRODUCTION
                   SECTOR
     FSWOUT  - RATE AT WHICH WORKERS LEAVE FOOD SUPPLY
                   SECTOR
     FSWI    - NUMBER OF WORKERS IN FOOD PRODUCTION
                   INITIALLY


FSWINR.KL=CLIP(FSWINA.K,0,DISFSW.K,0)              75, R
     FSWINR  - RATE AT WHICH WORKERS ENTER FOOD PRODUCTION
                   SECTOR
     FSWINA  - CALCULATION FOR WORKERS ENTERING FOOD
                   PRODUCTION SECTOR
     DISFSW  - DISCREPANCY BETWEEN DESIRED & ACTUAL FOOD
                   TRANSPORT WORKERS


FSWINA.K=MAX(0,WP.K*PDFSW.K*FSWDF)                 76, A
FSWDF=.8 DELAY                                     76.1, C
     FSWINA  - CALCULATION FOR WORKERS ENTERING FOOD
                   PRODUCTION SECTOR
     WP      - POOL OF WORKERS IN THE SYSTEM NOT EMPLOYED
     PDFSW   - PERCENT OF FOOD SUPPLY WORKERS DESIRED
     FSWDF   - DELAY FACTOR FOR TRANSFERRING WORKERS TO
                   FOOD PRODUCTION SECTOR


DISFSW.K=DFSW.K-FSW.K                              77, A
     DISFSW  - DISCREPANCY BETWEEN DESIRED & ACTUAL FOOD
                   TRANSPORT WORKERS
     DFSW    - DESIRED NUMBER OF FOOD SUPPLY WORKERS
     FSW     - THE FOOD SUPPLY WORKERS


DFSW.K=PDFSW.K*WA.K                                78, A
     DFSW    - DESIRED NUMBER OF FOOD SUPPLY WORKERS
     PDFSW   - PERCENT OF FOOD SUPPLY WORKERS DESIRED
     WA      - TOTAL NUMBER OF WORKERS AVAILABLE IN THE
                   SYSTEM


PDFSW.K=FSWD.K/(IFWD.K+CWD.K+FTWD.K+FSWD.K)        79, A
     PDFSW   - PERCENT OF FOOD SUPPLY WORKERS DESIRED
     FSWD    - DEMAND FOR FOOD SUPPLY WORKERS
     IFWD    - DEMAND FOR IP PRODUCTION WORKERS
     CWD     - DEMAND FOR CAPITAL WORKERS
     FTWD    - DEMAND FOR FOOD TRANSPORTATION WORKERS
```

```
FSWOUT.KL=CLIP(0,FSWOUA.K,DISFSW.K,0)                      80, R
    FSWOUT - RATE AT WHICH WORKERS LEAVE FOOD SUPPLY
                SECTOR
    FSWOUA - CALCULATION FOR WORKERS LEAVING FOOD SUPPLY
                SECTOR
    DISFSW - DISCREPANCY BETWEEN DESIRED & ACTUAL FOOD
                TRANSPORT WORKERS


FSWOUA.K=-DISFSW.K*FSWDF                                   81, A
    FSWOUA - CALCULATION FOR WORKERS LEAVING FOOD SUPPLY
                SECTOR
    DISFSW - DISCREPANCY BETWEEN DESIRED & ACTUAL FOOD
                TRANSPORT WORKERS
    FSWDF  - DELAY FACTOR FOR TRANSFERRING WORKERS TO
                FOOD PRODUCTION SECTOR


FSWD.K=DFP.K/(PPFSWN*FSWPM.K)                              82, A
    FSWD   - DEMAND FOR FOOD SUPPLY WORKERS
    DFP    - DESIRED LEVEL OF FOOD PRODUCTION
    PPFSWN - AMOUNT OF FOOD PRODUCED PER FOOD SUPPLY
                WORKER NORMALLY
    FSWPM  - FOOD SUPPLY WORKER PRODUCTIVITY  (HEALTH
                AND FOOD SHORTAGES)


IPCINF.K=IPCPUF*FPR.JK                                     83, A
IPCPUF=.00025 UNITS                                        83.1, C
    IPCINF - INTERMEDIATE PRODUCTS CONSUMED IN FOOD
                PRODUCTION
    IPCPUF - INTERMEDIATE PRODUCTS CONSUMED PER UNIT
                FOOD PRODUCED
    FPR    - RATE AT WHICH FOOD IS PRODUCED


IPCINT.K=IPCPUT*FSR.JK                                     84, A
IPCPUT=.00025 UNITS                                        84.1, C
    IPCINT - INTERMEDIATE PRODUCTS CONSUMED IN FOOD
                TRANSPORTATION
    IPCPUT - INTERMEDIATE PRODUCTS CONSUMED PER UNIT
                FOOD TRANSPORTED
    FSR    - RATE AT WHICH FOOD IS SHIPPED


    **************************************************************
          MATCHED FOOD SUPPLY SECTOR
    **************************************************************


MFS.K=MFS.J+(DT)(FAR.JK-FCR.JK)                            85, L
MFS=MFSI                                                   85.1, N
MFSI=400E3 LBS                                             85.2, C
    MFS    - THE QUANTITY OF FOOD THAT IS MATCHED WITH
                DEMAND
    FAR    - RATE AT WHICH FOOD ARRIVES TO CONSUMERS
    FCR    - RATE AT WHICH MATCHED FOOD IS BEING
                CONSUMED
    MFSI   - AMOUNT OF MATCHED FOOD FOOD SUPPLY (IN
                CONSUMER HANDS) INITIALLY
```

```
FAR.KL=FIT.K/TRANSD.K                                      86, R
     FAR     - RATE AT WHICH FOOD ARRIVES TO CONSUMERS
     FIT     - FOOD ORDERED FROM FOOD SUPPLY SECTOR IN
                  TRANSIT TO MATCHED
     TRANSD  - TOTAL FOOD TRANSPORTATION DELAY


FIT.K=FIT.J+(DT)(FSR.JK-FAR.JK)                            87, L
FIT=FITI                                                   87.1, N
FITI=440E3                                                 87.2, C
     FIT     - FOOD ORDERED FROM FOOD SUPPLY SECTOR IN
                  TRANSIT TO MATCHED
     FSR     - RATE AT WHICH FOOD IS SHIPPED
     FAR     - RATE AT WHICH FOOD ARRIVES TO CONSUMERS
     FITI    - FOOD IN TRANSIT PIPELINE TO CONSUMERS
                  INITIALLY


TRANSD.K=TRAND+IFFTD.K                                     88, A
     TRANSD  - TOTAL FOOD TRANSPORTATION DELAY
     TRAND   - PHYSICAL DELAY IN TRANSPORTING FOOD TO
                  CONSUMERS
     IFFTD   - FOOD TRANSPORTATION DELAY DUE TO
                  INTERMEDIATE PRODUCT SHORTAGE


IFFTD.K=CLIP(0,2,IF.K-IFB.K,0)                             89, A
TRAND=1 MONTH                                              89.1, C
     IFFTD   - FOOD TRANSPORTATION DELAY DUE TO
                  INTERMEDIATE PRODUCT SHORTAGE
     IF      - INTERMEDIATE PRODUCTS (FUEL, TRUCKS,
                  TRACTORS, ETC.)
     IFB     - THE BACKORDERS (BACKLOG) FOR INTERMEDIATE
                  PRODUCTS
     TRAND   - PHYSICAL DELAY IN TRANSPORTING FOOD TO
                  CONSUMERS


FCR.KL=MAX(0,MIN(MFS.K,FCPP.K*PTOTAL.K))                   90, R
     FCR     - RATE AT WHICH MATCHED FOOD IS BEING
                  CONSUMED
     MFS     - THE QUANTITY OF FOOD THAT IS MATCHED WITH
                  DEMAND
     FCPP    - AMOUNT OF FOOD CONSUMED PER PERSON
     PTOTAL  - TOTAL POPULATION OF SYSTEM


PTOTAL.K=CW.K+FSW.K+IFW.K+FTW.K+OTHER.K+WP.K               91, A
     PTOTAL  - TOTAL POPULATION OF SYSTEM
     CW      - THE CAPITAL SECTOR WORKERS
     FSW     - THE FOOD SUPPLY WORKERS
     IFW     - THE INTERMEDIATE PRODUCTS WORKERS
     FTW     - THE FOOD TRANSPORT WORKERS
     OTHER   - NON-WORKER POPULATION
     WP      - POOL OF WORKERS IN THE SYSTEM NOT EMPLOYED


OTHER.K=OTHER.J+(DT)(ONCR.JK)                              92, L
OTHER=OTHERI                                               92.1, N
OTHERI=6000 PEOPLE                                         92.2, C
     OTHER   - NON-WORKER POPULATION
     ONCR    - OTHER NET CHANGE RATE
     OTHERI  - NON-WORKER POPULATION INITIALLY
```

```
ONCR.KL=NCR*OTHER.K                                      93, R
NCR=0.0                                                  93.1, C
     ONCR    - OTHER NET CHANGE RATE
     NCR     - NET CHANGE RATE
     OTHER   - NON-WORKER POPULATION


FCPP.K=MIN(130,CLIP(SFCPP.K-DFRPP,MFAPP.K-DFRPP,         94, A
     MFAPP.K,SFCPP.K))
     FCPP    - AMOUNT OF FOOD CONSUMED PER PERSON
     SFCPP   - NSL
     DFRPP   - DESIRED FOOD CONSUMPTION RATE PER PERSON
     MFAPP   - AMOUNT OF MATCHED (ON HAND) FOOD AVAILABLE
                 PER PERSON


MFAPP.K=MFS.K/PTOTAL.K                                   95, A
DFRPP=0                                                  95.1, C
     MFAPP   - AMOUNT OF MATCHED (ON HAND) FOOD AVAILABLE
                 PER PERSON
     MFS     - THE QUANTITY OF FOOD THAT IS MATCHED WITH
                 DEMAND
     PTOTAL  - TOTAL POPULATION OF SYSTEM
     DFRPP   - DESIRED FOOD CONSUMPTION RATE PER PERSON


SFCPP.K=NSL*SUBM.K                                       96, A
NSL=40 LBS                                               96.1, C
     SFCPP   - NSL
     SUBM    - SUBSISTENCE EXPECTATIONS MULTIPLIER


SUBM.K=TABHL(SUBMT,TIME.K,0,LENGTH,LENGTH)               97, A
     SUBM    - SUBSISTENCE EXPECTATIONS MULTIPLIER


FSHORT.K=MAX(0,(NFCPP-FCPP.K)/NFCPP)                     98, A
NFCPP=122 LBS                                            98.1, C
SUBMT=1/3                                                98.2, T
     FCPP    - AMOUNT OF FOOD CONSUMED PER PERSON


MFSB.K=MAX(0,MFSORR.JK-FCR.JK)                           99, A
     MFSB    - THE SHORTAGE OF MATCHED FOOD IN MATCHED
                 FOOD SUPPLY
     MFSORR  - MATCHED FOOD SUPPLY ORDER RECEIVING RATE
                 (DEMAND FOR FOOD)
     FCR     - RATE AT WHICH MATCHED FOOD IS BEING
                 CONSUMED


MFSORR.KL=SFCPP.K*PTOTAL.K                               100, R
     MFSORR  - MATCHED FOOD SUPPLY ORDER RECEIVING RATE
                 (DEMAND FOR FOOD)
     SFCPP   - NSL
     PTOTAL  - TOTAL POPULATION OF SYSTEM


MFSOR.KL=DMFS.K*C205                                     101, R
C205=1                                                   101.1, C
     MFSOR   - MATCHED FOOD SUPPLY ORDER RATE
     DMFS    - DEMAND FOR MATCHED FOOD SUPPLY
     C205    - MULTIPLIER FOR ORDERING MATCHED FOOD SUPPLY
```

```
DMFS.K=MFSORR.JK                                          102, A
    DMFS    - DEMAND FOR MATCHED FOOD SUPPLY
    MFSORR  - MATCHED FOOD SUPPLY ORDER RECEIVING RATE
              (DEMAND FOR FOOD)


  ********************************************************
  WORKER POOL SECTOR
  ********************************************************

WP.K=WP.J+(DT)(IPWOUT.JK+CWOUTR.JK+FSWOUT.JK+             103, L
   FTWOUT.JK-IPWINR.JK-CWINR.JK-FSWINR.JK-FTWINR.JK+
   WPSR.JK)
WP=WPI                                                    103.2, N
WPI=0                                                     103.3, C
    WP      - POOL OF WORKERS IN THE SYSTEM NOT EMPLOYED
    IPWOUT  - RATE AT WHICH WORKERS LEAVE IP SECTOR
    CWOUTR  - RATE AT WHICH WORKERS LEAVE CAPITAL SECTOR
    FSWOUT  - RATE AT WHICH WORKERS LEAVE FOOD SUPPLY
              SECTOR
    FTWOUT  - RATE AT WHICH WORKERS LEAVE FOOD
              TRANSPORTATION SECTOR
    IPWINR  - RATE OF WORKERS ENTERING IP SECTOR
    CWINR   - RATE OF WORKERS ENTERING CAPITAL SECTOR
    FSWINR  - RATE AT WHICH WORKERS ENTER FOOD PRODUCTION
              SECTOR
    FTWINR  - RATE OF WORKERS ENTERING FOOD
              TRANSPORTATION SECTOR
    WPSR    - WORKER TRANSFER RATE BETWEEN REGIONS IN THE
              SYSTEM
    WPI     - INITIAL NUMBER OF WORKERS IN WORKER POOL


WPSR.KL=WPDF*DISCWP.K                                     104, R
WPDF=0 PERCENT                                            104.1, C
    WPSR    - WORKER TRANSFER RATE BETWEEN REGIONS IN THE
              SYSTEM
    WPDF    - DELAY FACTOR FOR TRANSFERRING WORKERS
              BETWEEN REGIONS
    DISCWP  - DISCREPANCY BETWEEN WORKERS AVAILABLE &
              DEMAND


DISCWP.K=TWD.K-WA.K                                       105, A
    DISCWP  - DISCREPANCY BETWEEN WORKERS AVAILABLE &
              DEMAND
    TWD     - TOTAL NUMBER OF WORKERS DEMANDED
    WA      - TOTAL NUMBER OF WORKERS AVAILABLE IN THE
              SYSTEM


TWD.K=CWD.K+IPWD.K+FSWD.K+FTWD.K                          106, A
    TWD     - TOTAL NUMBER OF WORKERS DEMANDED
    CWD     - DEMAND FOR CAPITAL WORKERS
    IPWD    - DEMAND FOR IP PRODUCTION WORKERS
    FSWD    - DEMAND FOR FOOD SUPPLY WORKERS
    FTWD    - DEMAND FOR FOOD TRANSPORTATION WORKERS
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